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Human subjects participated in this study after giving their free and informed consent. Investigators adhered to NAVHLTHRSCHCENINST 6500.2, 2 Aug 95, concerning the protection of human volunteers in medical research.

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EXECUTIVE SUMMARY

Problem. The U.S. Marine Corps is considering replacement of the ALL-Purpose Lightweight Individual Carrying Equipment (ALICE) with a commercially available backpack as part of the Marine Enhancement Program.

Objective. The objective of this study was to evaluate 13 commercially available load-bearing ensembles (LBE) used with the Individual Tactical Load-Bearing Vest (ITLBV) and compare these systems to the ALICE pack to determine the best load-to-individual interface for use by the U.S. Marine Corps. It was hypothesized that advances in commercial LBEs would offer a significant improvement over the ALICE pack effecting less muscle fatigue, fewer gait alterations, minimized postural changes, reduced metabolic effort, and minimized discomfort related to hand numbness. The information developed in this study will be used to recommend an LBE to the U.S. Marine Corps. This recommendation can be either a single available system or it can include features from many LBEs to be incorporated into a new design.

Approach. Evaluations of each LBE were performed biomechanically (gait analysis and electromyographically), physiologically (heart rate [HR] and oxygen consumption [Vo_2]), and subjectively (ratings based on comfort, fit, and pressure distribution over the torso). Intensity of effort (RPE) and postural maintenance strategies (NeuroCom®) both unloaded and loaded (before and after each exercise cycle) were also measured. Each subject completed 13 trials (once a week) using the ITLBV (9.1 kg) and a different LBE (36.4 kg). Subjects (n = 14) walked (2.5 mph @ 2% grade) for 4 hr (50 min/10 min walk/rest cycle) in a 70°F room. Prior to testing, each subject was measured for body composition, somatype, proportionality, peak Vo_2, baseline gait analysis, and posture. During each 4-hr test, Vo_2 was measured for 2 min at T = 20 min and T = 40 min during each hr of the test. Two 2-min walking segments were filmed at T = 5 min and T= 45 min. Surface electromyographical (EMG) readings were taken from the left gastrocnemius and left anterior tibialis muscles at the same time as the videos were filmed. HR was measured continuously and the subjects were asked to evaluate their RPE based on a 10 point scale and their backpack rating (comfort, fit, and ease-of-use) based on a 10 point scale (0 = worst, 10 = best).

Results. Body profiles created from anthropometric measurements indicate that this group of U.S. Marine Corps subjects had less fat and more muscle than the average individual for this age group (22.1 ± 4.3 yr). The group was very fit with a peak $Vo_2 = 4.56 \pm 0.62$ L•min^{-1}. Hydration was checked before each trial and was well maintained. The top eight rated backpacks were internal frame backpacks (internal = 6.8 ± 1.5, external = 4.7 ± 2.4, $p \leq 0.001$). There was no difference in the metabolic parameters between types of backpacks, but both HR and Vo_2 increased ($p \leq 0.05$) over the 4-hr duration indicating fatigue and recruitment of muscle to maintain pace. There was no significant increase in RPE over time. Analysis of EMG data indicated that the anterior tibialis muscle (load-acceptance on both foot strike and push-off) fatigued (indicated by an increased slope of RMS) more ($p \leq 0.05$) than the gastrocnemius (plantarflexon) muscle. The fatigue was greater in the higher rated backpacks than in the lower rated backpacks possibly indicating that the more favorable

backpacks place pressure on the legs rather than on the back. Analysis of the sensory organizational parameters indicated that fatigue does affect sensory receptors and postural balance muscles with the greatest effect being on the vestibular sensory receptors. The angle of trunk lean (angle between umbilicus and upper body) was 73 degrees for all backpacks. There was no difference between internal frame and external frame backpacks in terms of trunk lean which was probably due to extreme weight of the load carried.

Conclusions. The ALICE pack has many features that make it adaptable for use in military operations. However, the limitations of the pack and its role in causing pain and discomfort (e.g., rucksack paralysis) is sufficient reason to develop a new backpack for military use. The results of this study and other studies indicate that the load needs to be carried as close to the center-of-mass of the user as is possible. However, the use of a pack that distributes the load around the center-of-mass (e.g., equally in the front and back) will not prove feasible under military conditions. Therefore, the backpack frame that is chosen to meet the future needs of the military should transfer the weight to the hips and off the shoulders, have sufficient load adjustment straps that allow the load to be pulled into the body (to minimize changes in center-of-mass), and correctly fit the individual. The correct fitting (torso length) of the backpack frame to the individual was the most important factor in determining comfort and acceptance of a backpack. An otherwise excellent backpack that does not fit the individual will be uncomfortable and may be a precursor to injury in the long run. Therefore, the backpack frame that is chosen will require multiple sizes and adjustability within each size. The foam in the waist belt needs to be of sufficient density to support the load (e.g., resist compression and deformation) and the waist belt connecting strap needs to be sufficiently large to prevent rollover. The lumbar pad needs to be firm but not so stiff it will cause lower back problems. The vertical frame components (stays) need to be supported by horizontal frame components to keep the pack in its intended shape irrespective of the size of the load. Design of the vertical frame components in order to transfer the weight to the sides of the hips rather than just to the low back would spread the pressure to the top of the hips and further reduce the potential for low back problems. There is not a single commercial backpack ensemble that meets all of these requirements, but there are several commercial ensembles that incorporate some of the requirements and could be a good starting point for a new backpack system.

Recommendations: The best course of action is to design a new backpack system that will incorporate the following features. The frame should be designed to be near the center-of-mass (e.g., an internal frame design), be able to be fitted and adjusted, and allow the pack to be removed quickly while the individual continues to wear the load carriage system (frame, shoulder straps, and waist belt) which now incorporates pockets for water and ammo. By separating the pack from the load carriage components, it makes it feasible to issue a load carriage system to each individual as part of their standard equipment and then a backpack (different volumes for different uses) could be attached as needed. The attachment of the pack could involve the use of velcro or some other combination of fasteners. This system would move the weight off of the shoulders, improve the center-of-mass of a loaded pack, decrease the incidence of injuries caused by ill-fitted equipment, and still allow the light infrantryman to perform their military tasks which involve movement and warfighting.

INTRODUCTION

The transportation of gear, weapons, and equipment over rough terrain makes carrying backpacks essential for military use. Determining safe and efficient methods of load carriage has been a subject of investigation for many years (Datta & Ramanathan, 1971; Epstein et al., 1988; Kinoshita, 1985; Keren et al., 1981; Kirk & Schneider, 1992; Legg et al., 1992; Martin & Nelson, 1985). Martin and Nelson (1985) have shown that a given load can be carried most economically when centered around the body. Bloom and Woodhull-McNeal (1987) found that with an internal frame pack, the frame is an integral part of the pack in which the center of volume is both lower and closer to the body than in an external frame pack where the frame is outside and independent of the pack. It was determined that the double pack, which distributes the load to the front and back of the trunk, was the most effective mode of transport, both mechanically and physiologically, but it may not be practical for military use (Datta & Ramanathan, 1971; Legg, 1985; Kinoshita, 1985).

Pierrynowski et al. (1981) concluded that biomechanical analysis of load carriage can provide not only mechanical energy information but also information possibly useful in the design of load carriage systems. Using a 19.5 kg load, Bobet and Norman (1984) found that midback placement actually caused muscle activity in the lower back to decrease. The extension movement created by the load on the back offset the normal flexion movement caused by the head, arms, and trunk.

Holewijn (1990) measured skin pressure under the shoulder strap of a backpack and found levels exceeding three times the threshold for skin and tissue irritation. Rate of Preceived Exertion (RPE) for the chest, shoulders, and legs was found to increase with no corresponding increases in physiological exertion (Kirk & Schneider, 1992). When evaluating six different methods of load carriage, Legg (1985) found it difficult to physiologically distinguish the "best" way to carry a load and reported that subjects chose the double pack with regard to RPE and comfort. Subjective rating to determine acceptable loads was also suggested by Legg and Myles (1981).

The U.S. Marine Corps' present load carrying system is the All-Purpose Lightweight Individual Carrying Equipment (ALICE) pack coupled with either an H-harness or Individual Tactical Load-Bearing Vest (ITLBV) to carry the warfighting supplies. The ALICE pack is used to carry loads up to 37 kg and use of the ITLBV can increase the load to 55 kg (120 lb). The ITLBV distributes some of the load around the center torso to allow an increased total load as well as augmenting postural balance. This concept of using the ITLBV will be continued with the proposed new pack. The ALICE pack has a high risk of precipitating injuries because the weight of the load is carried primarily on the shoulders, which compresses the nerves in the brachial plexus region. Since many nerves innervate this area, hand and forearm numbness is quite common. Rucksack palsy, a muscle atrophying condition in which muscle weakness occurs in the deltoids, supraspinatus, infraspinatus, and occasionally the wrist extensors, can result from heavily loaded backpacks being carried in this manner. Sensory loss, although not as common, may also occur in the shoulder area (Daube, 1969).

The objective of this study was to evaluate 13 commercially available Load-Bearing Ensembles (LBE), with the presently utilized ITLBV. These results were compared to the ALICE pack load carriage system to determine the best load-to-individual interface for use by the Marine Corps. Evaluations were done biomechanically (gait analysis and electromyographically), physiologically (heart rate and oxygen consumption), and subjectively (ratings based on comfort, fit, and pressure distribution over the torso). Subjects were asked to determine their intensity of effort by RPE scales (Borg scale). In addition, stationary postural balance strategy tests were performed to determine if any packs caused fewer changes in postural maintenance strategies due to muscular fatigue. Comparisons were made between unloaded tests and before and after each exercise session (loaded). These comparisons were done to determine if fatigue affected balance from any or all of the somatosensory, visual, or vestibular sensory systems. It is hypothesized that advances in commercial load-bearing ensembles would offer a significant improvement over the current ALICE pack, effecting less muscle fatigue, fewer gait alterations, minimized postural changes, reduced metabolic effort, and minimized discomfort associated with hand and forearm numbness. This would result in increased efficiency and reduced risk of injury under heavily loaded conditions.

The 13 commercially available load-bearing ensembles (backpacks) chosen (by U.S. Marine Corps) for this evaluation consisted of 10 internal and 3 external frame packs. All packs are listed in Table 1 and pictured in Figures 1 through 14 with both full posterior view, and a three-quarter sideview. Packs were of two categories (internal and external) frames. Packs were numbered and assigned randomly. All packs tested featured at least 5,000 cubic inch capacity, and some offer up to five sizes, extra small to extra large, to accommodate differences in subjects heights and widths.

Table 1. Number assignments for backpacks tested.

Internal Frames	Pack No.	External Frames	Pack No.
Pioneer	1	TL 7000XPD	5
Elite	2	Radial Light	9
Vital Experience	3	Evolution Flo-form	10
Phoenix	4	ALICE	13
Frostfire	6		
Robson	7		
Deva	8		
Stillwater	11		
Tawnee II	12		
Dolomite	14		

Internal Frame Backpacks.

The Pioneer (Figure 1) is manufactured by Modan Industries, Ltd., and features an automatic adjustable stabilizer system which allows adjustment of the height of the shoulder straps while walking. It has double-layer S-shaped shoulder pads which are covered by a tension distribution panel, V-shaped aluminum frame, and a "Super Flex" shock absorber. The hip belt has a "Gyro-Joint" that allows a three-dimensional freedom of movement, covered by the lumbar pad. It has a multi-layer padded hip belt, height adjustment cords and a quick release buckle, and a slider track to enable easy adjustments.

Figure 1. Pioneer backpack manufactured by Modan Industries, Ltd.

The Elite I (Figure 2) and Frostfire II (Figure 3) made by MountainSmith feature a many compartment system with detachable accessory pouches. It has seams that are taped to prevent fraying. These packs feature two-way adjustments for torso height and width. They have floating torso plates that allow for asymmetrical shoulder anatomy and a waist belt designed to eliminate pressure points by layered padding. The suspension system allows adjustment to angle of load carriage as well as a stabilizer strap to prevent bounce and sway. The Elite series features a flotation waist belt that has a pressureless pocket to remove stress from the hipbone area. Both packs have accessory packs, tool tie-off points, and trampoline side pockets. The volume of the pack is dependent on the series and ranges from 98,946 cu cms (6,037 cu in) to 131,070 cu cms (7,997 cu in). The Elite series is heavier than the Frostfire series (3.15 kg vs. 2.44 kg).

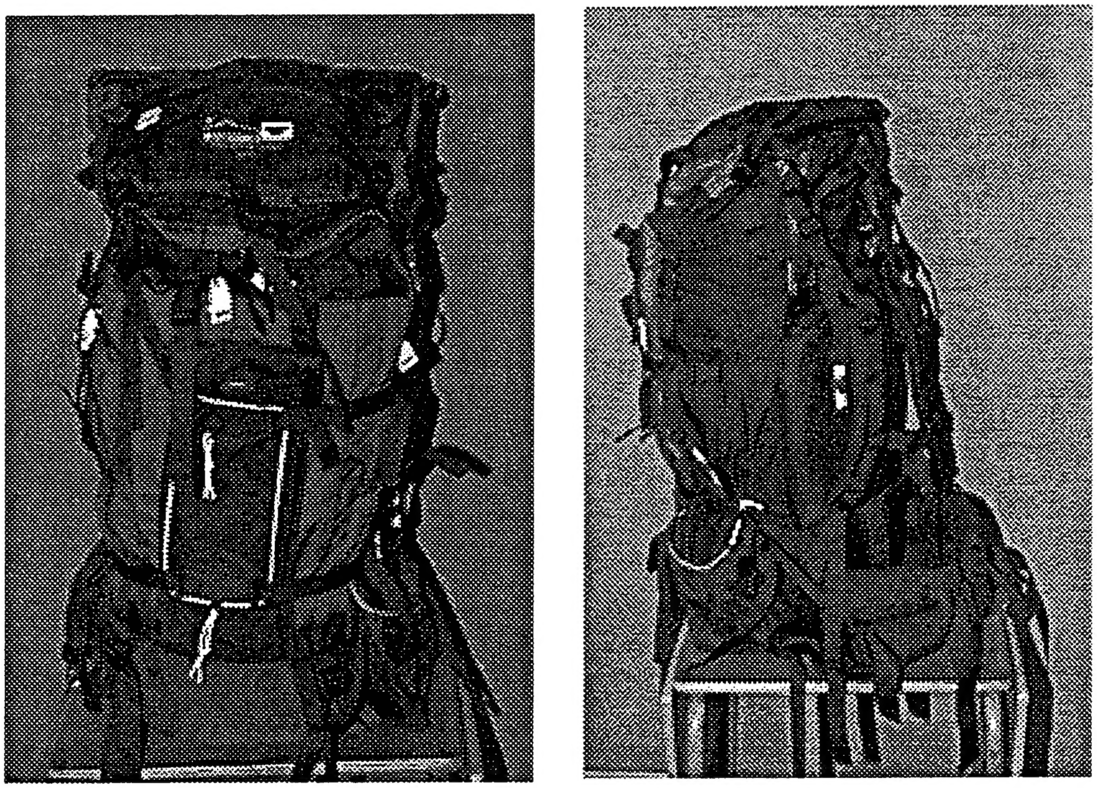

Figure 2. Elite I backpack manufactured by MountainSmith.

Figure 3. Frostfire II backpack manufactured by MountainSmith.

The Vital Experience (Figure 4) made by Natural Balance is a body hugging design that has a vertical S-shape to match the contours of the back which keeps the load close to the wearer's center of gravity. The frame can be adjusted for precise fit while allowing whole-body contact area ventilation through reticulated foam under the shoulder straps, hip belt, and backpanel. It has a patented Bicresent™ hip belt that puts weight on top of the hipbones. The tri-pod frame distributes the load evenly around the circumference of the hips. The flexible connecting points for the pack to the hip belt allows the user to twist and bend independently of the pack. This single compartment expandable top-loading backpack has a capacity of 62,282 cu cms (3,800 cu in) to 109,813 cu cms (6,700 cu in) (size dependent) while weighing approximately 2.1 kg.

Figure 4. Vital Experience backpack manufactured by Natural Balance.

The Phoenix (Figure 5) and Deva (Figure 6) made by Trigon both contain shoulder pad yokes that connect directly to the main aluminum frame stay for stability. The hip belt is large and contoured from single density foam for nonrestrictive fit that distributes the weight of the load over a greater area for comfort. The Phoenix has a 98,340 cu cms (6,000 cu in) carrying capacity and weighs 3.3 kg, in addition it has dual haul loops, waterbottle pockets, lash points for skis, ice axes, avalanche shovels, three lightweight aircraft grade aluminum stays, and a fiberglass wand positioned horizontally on the upper portion of the frame to enhance stability and fit. The Deva contains the same features as the Phoenix but with 90,145 cu cms (5,500 cu in) capacity it is a lighter pack weighing only 2.9 kg.

Figure 5. Phoenix backpack manufactured by Trigon.

Figure 6. Deva backpack manufactured by Trigon.

The Robson (Figure 7) made by Gregory Mountain Products features adjustable shoulder, hip, and sternum stabilizers. A reinforced frame sheet provides flexible support and helps to protect the back. The Flo-Form® back panel sculpted foam pads have molded air channels for ventilation. The load control hip belt provides efficient load transfer to the hips. The Flo-Form® shoulder harness allows for a contoured fit around the shoulders and hips. The twin carbon fiber stays are angled in a V-configuration for a comfortable head clearance. There are multiple sizes (X-small to X-large) available and there are adjustments (by reattaching shoulder straps) for the torso length within each pack size.

Figure 7. Robson backpack manufactured by Gregory Mountain Products.

The Stillwater (Figure 8) manufactured by Dana Design is made with a high-density polyethylene framesheet and an aircraft aluminum stay designed to enhance stability of the frame. It incorporates carbon fiber bows (located at side of frame) that create a springy flex to uniformly load the hip belt. The pack comes in sizes ranging from X-small to X-large with appropriate scaling of lumbar size, length of frame stay, contour of body panel, and relationship of Arcflex™ curve to the back. The Contour Molded Hip Belts™ are molded to allow for extremes of human hip shapes. The lumbar padding is dual density foam backed by the framesheet which distributes the pack weight across the back. The reticulated foam used as padding for the upper back allows ventilation of the back. Additional head space is created by a concave wedge at the top of the pack.

Figure 8. The Stillwater backpack manufactured by Dana Design.

The Tawnee II (Figure 9) made by Kelty Inc., uses 7001-T6 aircraft aluminum alloy for its frame and incorporates a high-density polyethylene suspension panel which contours the load around the body. This backpack features a precurved S-shaped shoulder harness and a double padded conical waist belt. It is available in three sizes (regular to X-large) and does not allow adjustment within the sizes. The weight of the backpack ranges from 2.52 kg to 2.61 kg and the capacity from 72,279 cu cms (4,410 cu in) to 106,125 cu cms (6,475 cu in).

The Dolomite (Figure 10) made by North Face, Inc., features a high-density polyethylene (HDPE) frame stabilizer sheet, two 6061-T6 aluminum alloy stays, a solid Delrin rod load transfer strut, and molded foam shoulder harness and hip belt. The stays are placed in webbing tracts (sewn directly to the HDPE) and the top control straps attach to the top of each stay. The load transfer strut connects the top of the HDPE stabilizer to the hip belt and redirects downward forces generated by the pack load toward the user's center of gravity. The pack comes in sizes from small to large which handle torso lengths from 12 to 25 inches. The pack weight ranges from 2.89 kg to 3.37 kg and the capacity from 75.394 cu cms (4,600 cu in) to 95,062 cu cms (5,800 cu in).

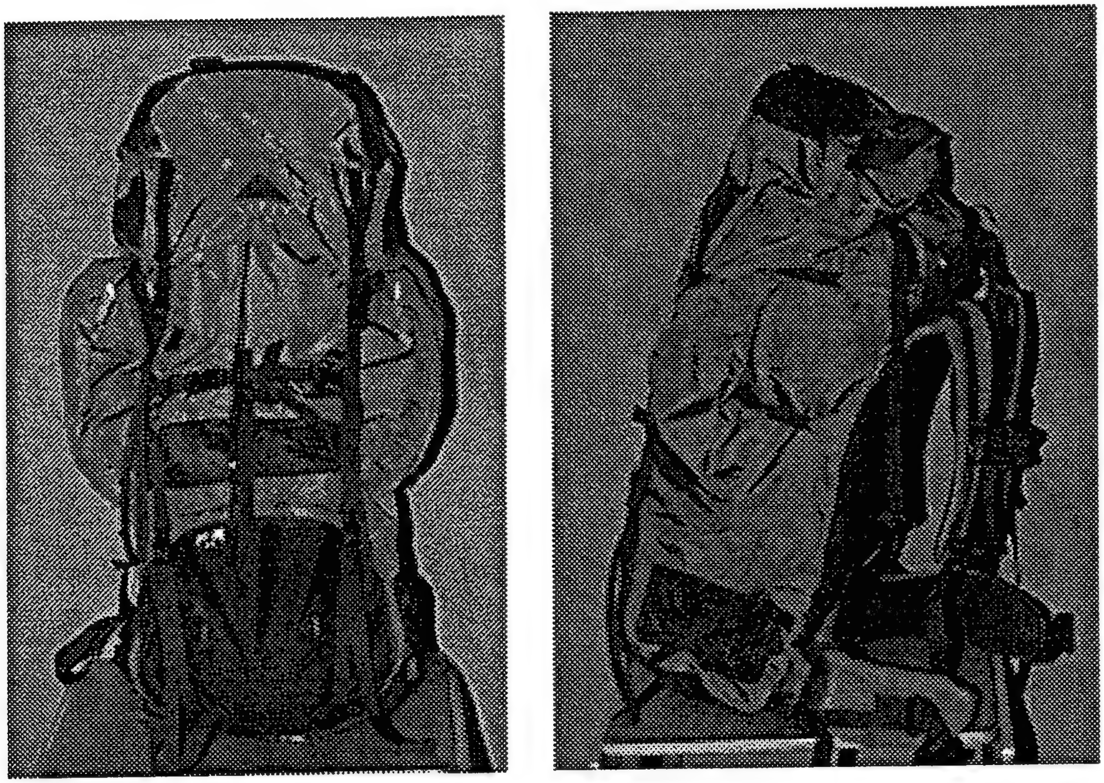

Figure 9. The Tawnee II manufactured by Kelty, Inc.

Figure 10. The Dolomite backpack manufactured by North Face, Inc.

External Frame Backpacks.

The Peak I (Figure 11) made by Coleman features a Kevlar-reinforced nylon composite frame that is designed to bend and twist in sync with the user's movements (Live-Load™) to achieve a controlled flexibility. The outer margin of the frame has a series of slots to accept the pack connectors or straps (Lash-Tab™) which allows great latitude for attachments and adjustments. The frame (torso length) is adjustable by reattaching the upper ends of the shoulder straps to a perforated cross plate (allows about 8 inches of adjustment). This frame type enables the Peak I to fit individuals from 5 feet 3 inches to 6 feet 5 inches in height. The size of the pack attached to the frame can be varied to allow for large or small loads.

Figure 11. The Peak I backpack manufactured by Coleman.

The Radial Light (Figure 12) made by Kelty Inc., features a telescoping frame (6063-T832 aluminum alloy) that allows a certain amount of adjustment for individual height. The attachment of the shoulder straps can be positioned (to accommodate different torso lengths) on cross bars that are about 5 inches apart in a vertical direction. The upper ends of the shoulder straps can be moved in a horizonal direction (3 inches) and reattached to widen the yolk. The waist belt is a multilayered, full-wrap belt constructed of pressure-sensitive foam. The capacity of the pack ranges from 57,365 cu cms (3,500 cu in) to 90,718 cu cms (5,535 cu in) and the weight is 2.96 kg.

Figure 12. The Radial Light backpack manufactured by Kelty Inc.

The Evolution Flo/Form (Figure 13) made by Gregory Mountain Products has aluminum side rails (T-832 alloy) connected by Flex•Form™ cross members made from high-density polyethylene and ST801 nylon polymers. The frame incorporates a shoulder harness adjustment panel to allow adjustments for torso length within sizes. The adjustment panel and the lower cross members are covered with a reticulated foam with channels to facilitate ventilation. A tri-density foam lumbar pad is attached to the frame and the same foam is used in the waist belt. The frame is available in sizes (X-small to X-large) which will accommodate torso lengths of 14 inches to 21 inches or larger. The pack frame uses a lower shelf to support a sleeping bag and this shelf allows the pack to stand in an upright position when not being carried.

The ALICE pack (Figure 14) is manufactured by several different companies under contract to the government. This pack is the standard issue for land-based military units to carry medium loads. The pack can be used either with or without a frame. The frame is constructed of tubular aluminum and has reinforcing metal straps. There is only one way to attach the pack and the shoulder and waist straps so there is no allowance for different sizes of users. The waist strap (not padded) is available, but it serves no purpose for load carriage. The weight is supported by the shoulder straps. The pack is designed to be worn in conjunction with the ITLBV which also has shoulder pads that serve to further cushion the shoulder straps of the ALICE pack.

Figure 13. The Evolution Flow/Form backpack manufactured by Gregory Mountain Products.

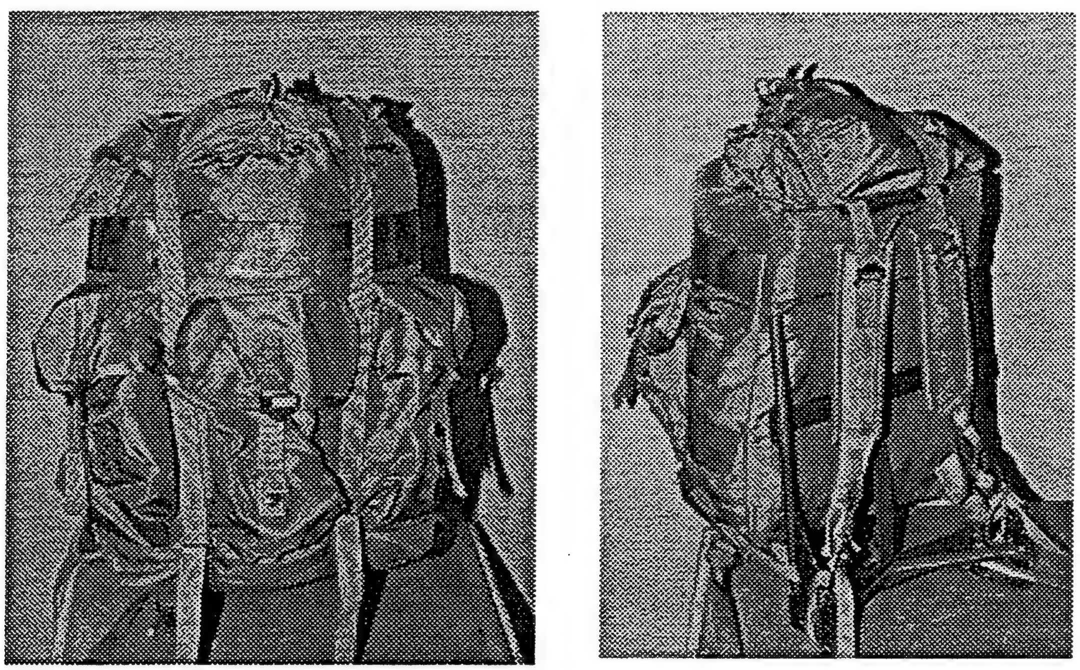

Figure 14. ALICE Pack.

METHODS

Subjects. Fourteen male U.S. Marines (1st LAR BN, Camp Pendleton, CA) signed an informed consent and volunteered as subjects. Prior to participation, each subject was medically cleared according to provisions of NAVHLTRSCHCENINST 6500.2. Physical characteristics ($\bar{X} \pm$ SD) of the subjects can be seen in Table 2.

Table 2. Physical characteristics of subjects.

Age	22.1 ± 4.3 yrs
Height	176.4 ± 6.0 cm
Weight	82.0 ± 10.2 kg
Body Fat	15.1 ± 4.2 %
Lean Body Weight	69.9 ± 6.9 kg
Fat Weight	12.7 ± 4.6 kg
$\dot{V}O_2max$	4.56 ± 0.62 L•min^{-1}
Sum of Six Skinfolds	88.8 ± 25.4 mm

Design. Volunteers performed 13 (using 1 of 13 commercial systems or the current ALICE pack) separate hikes once a week at the same time of day with four 50 min/10 min walk/rest cycles on a treadmill at a speed of 2.5 mph (effective speed = 4.03 km•hr^{-1}) at a grade of 2%. A different LBE (pack weight = 36.4 kg and ITLBV weight = 9.1 kg) was used for each trial. The parameters included measurements in the areas of: metabolic, biomechanical, and psychological.

Experimental Protocol. Prior to testing the load carriage systems, each subject was measured for the following: body composition, somatotype, proportionality measurements, maximum oxygen uptake, baseline gait analysis, and postural measurements.

Measurements and Initial tests. Anthropometric measures included: stature; weight; girths (neck, shoulder, chest, abdomen, hip, arm, calf, ankle); lengths (leg, trunk); breadths (biacromium, biiliac, bitrochanter, transverse chest, elbow, ankle); and skinfold thickness (subscapular, triceps, suprailiac, thigh, calf, abdominal). A graded exercise treadmill test was used to determine maximal oxygen consumption ($\dot{V}O_2max$). Baseline gait analysis was performed using a 1-min video of the subject walking on the treadmill with no load, for future comparisons for trunk angle displacement, velocity, and acceleration of shoulders and hips. Subjects were tested on the NeuroCom Equitest System® to determine center of gravity shifts and postural balance changes in an unloaded state.

Volunteers were instructed to maintain normal hydration throughout the course of the testing period, and water intake was ad lib during the exercise sessions. Multiple-frequency bioelectrical impedance was used to determine body fluid compartment volumes (total-body water [TBW], extracellular water [ECW], and intracellular water [ICW]) to ensure similar hydration levels for each trial. The volunteers wore shorts, T-shirts, combat boots, and a Kevlar helmet for all trials.

Subjects were tested on the NeuroCom EquiTest® prior to and immediately after each exercise session to determine their loaded shifts in center of gravity (COG) and balance strategy. A second test was administered immediately after the exercise session to examine how muscular fatigue contributed to changes in postural maintenance strategy.

Subjects were fitted with reflective markers (shoulder, helmet, hip, knee, and ankle) for video analysis, a heart rate (HR) monitor and electrocardiographic (ECG) electrodes. ECG data was collected during oxygen uptake measurement and used to verify HR monitors. Surface electrodes were used to record electromyographic (EMG) signals from the left gastrocnemius and left anterior tibialis muscles.

All testing occurred at the Naval Health Research Center (NHRC) laboratory in Building 287, Naval Training Center (NTC) and was conducted in an air-conditioned room maintained at 70°F. Oxygen consumption ($\dot{V}O_2$) was determined using a breath-by-breath open-circuit spirometry (Morgan or SensorMedics metabolic system) to determine the volume of oxygen, volume of carbon dioxide, and air volume in the subjects expired air. Two 2-min $\dot{V}O_2$ measurements were taken at T = 20 min and T = 40 min of each hr of the march cycle. Subjects were asked to provide a rate of perceived exertion (RPE) based on the Borg 10-point scale, and a pack rating based on comfort, fit and pressure over the torso, shoulders, and hips (0 = low and 10 = high). During each hour of the march cycle, two 2-min walking segments were filmed using two Panasonic SVHS cameras at T = 5 min and T = 40 min. A MikroMat® gait analysis system was used to analyze gait mechanics of the individuals recorded on the video tapes.

Procedures.

Gait Analysis. Two Panasonic model AG-450 SVHS cameras were placed at right angles to each other to record side and rear views of subjects walking on the treadmill. Reflective markers were used to determine joint position with a linear scale of 5 feet placed in the plane of activity. Video signals were analyzed using MikroMat® software (Mega, Inc.) to determine various biomechanical parameters. Trunk angle, defined as the angle between an imaginary horizontal line drawn through the umbilicus and the upper torso, was determined using the side view. The shoulder marker placed at the subject's left acromion process was compared to the left hip marker, placed at the subject's trochanter. In addition, 10 s comparisons were made between the first and last hour for each subject's vertical and horizontal velocities, accelerations, and displacements for their hips and shoulders.

Electromyography. Surface electrodes (5 mm Ag-AgCl) were attached to the skin using adhesive tape. EMG signals were recorded on a ME3000P (Mega, Inc.) for 2 min at min 5 and min 40 of each

hour. Fatigue analysis was conducted by analyzing change in the slope of the amplitude (root mean square [RMS]) of EMGs. Comparisons were made of the change in amplitude at the end of the first and last hour.

Oxygen Consumption. $\dot{V}O_2$ was measured by open-circuit spirometry (Morgan Exercise Test Benchmark metabolic system) in a breath-by-breath mode at min 20 and min 45 of each walking cycle. The mouthpieces were disinfected (Control III®) after each exercise session. Expiratory air was analyzed for volume and percentages of oxygen and carbon dioxide and the values used to calculate $\dot{V}O_2$. Metabolic data provided information on level of work intensity and fuel source.

Bioelectrical Impedance. Impedance was measured with a bio-impedance spectrum analyzer system (Model 4000B, Xitron Technologies, Inc., San Diego, CA). Electrode sites were cleaned with alcohol, and four disposable, gel-foil type electrodes were attached to the supine subject. Electrodes were placed on the dorsal surfaces of the right hand at the level of the distal prominence of the radius and ulna, and the distal metacarpal joints; and on the right foot, across the medial and lateral malleoli, and distal metatarsal joints. Two of the electrodes introduced a painless, imperceptible signal (200 μA in a logarithmical spaced frequency sweep from 5 kHz to 500 kHz) into the deep tissues of the subject. The other two electrodes were the ground. These data were used to predict ECW and TBW by application of formulas generated by Xitron. ICW was calculated as the difference between TBW and ECW.

Heart Rate. Polar Advantage-XL Heart Rate Monitors® were attached to the subjects by electrodes placed on the chest. HR signals were transmitted to a wristwatch receiver and recorded and later downloaded to a computer.

Anthropometry. A fiberglass measuring tape with a tab was used for measuring girths. Skinfold thickness measurements were taken using Harpenden skinfold calipers. Breadths were measured with small and large sliding calipers, and lengths were assessed with the large sliding anthropometer. Fat-body mass (percent body fat) and lean-body mass was calculated using regression equations developed on naval personnel in previous NHRC studies (Hodgdon & Beckett, 1984) and other established equations from the literature (Jackson & Pollock, 1978). Proportionality (Ross & Marfell-Jones, 1991) and somatotype (Carter, 1980) was assessed using the above mentioned measurements. A body profile was calculated from body measurements. Each measurement was divided by a constant derived by a "reference man." The resulting score was termed a "d" score. Each d value, expressed as a percent of the sum of the measurements, was divided by 100 to obtain the value D. The deviation of the group of subjects (mean) from the reference individual was calculated as: $([d - D] \div D) \bullet 100$ and reported as Z scores (McArdle et al., 1986). These measurements will be incorporated into an NHRC data base on anthropometrical measurements in active-duty military personnel.

NeuroCom Equitest®. This test was used initially to determine the subjects postural balance strategy unloaded, and before and after each march with a loaded pack (Ledin & Ödkvist, 1993). The NeuroCom Equitest® apparatus consists of computer-controlled force plates (one for each foot)

and a visual surround (horizon) (Collins & DeLuca, 1995). During the different condition tests, the force plates and/or the surround can be fixed in place (immobile) or freely-movable with the motion of the subject. The dressed volunteer was instructed to stand inside the apparatus with his feet properly placed on the force plates. Each subject was required to perform a series of six different test conditions, each condition was performed two times, and the means of each trial were used for analysis. The first condition involved the subject standing quietly with eyes open and the floor plates and surround immobile. The second condition involved the subject standing quietly with eyes closed and the floor plates and surround immobile. The third condition involved the subject standing quietly with eyes open, the surround moving in sync with body sway, and the floor plates immobile. The fourth condition involved the subject standing quietly with eyes open, the surround immobile, and the floor plates freely movable with body sway. The fifth condition involved the subject standing quietly with eyes closed, the surround immobile, and the floor plates freely movable with body sway. The sixth condition involved the subject standing quietly with eyes open, the surround and the floor plates freely movable with body sway. An equilibrium score was calculated by comparing the angular difference between the subjects calculated maximum anterior to posterior center of gravity displacements to the theoretical maximum displacement, amplitude, frequency, direction, and regularity of subject sway. This reflects the strategy (ankle vs. hip) used to maintain balance and center of gravity. In addition , four sensory organization patterns were assessed individually. Somatosensory (SOM Test) (condition 2/condition 1) addressed the effect of visual cues on body sway, visual (VIS Test) (condition 4/condition 1) addressed the effect of inadequate somatosensory cues on body sway, vestibular (VEST Test) (condition 5/condition 1) addressed the effect of both the removal of visual cues and inaccurate somatosensory cues on body sway and visual preference, preference (PREF Test) (condition [3 + 6]/condition [2 + 5]) compared the effect of inaccurate visual cues and no visual cues on body sway.

Maximal Stress Test. This test was conducted on a motorized treadmill using an incremental graded exercise test protocol. The procedure was: following a 5-min resting baseline (seated), the subject walked or walked and jogged for 2-min stages depending on the subject's fitness level. The first stage was at 3.5 mph, second stage at 4.0 mph, and the third stage was increased to a comfortable speed for the subject. After this stage, speed was maintained constant and percent grade was increased 2% every 2 min until the criteria for $\dot{V}O_2max$ was achieved (i.e., no increase in hr or $\dot{V}O_2$ with an increase in workload, and/or a respiratory exchange ratio of greater than 1.00, and/or volitional exhaustion was reached.) After exercise, the speed and grade of the treadmill was reduced and the subject continued to walk for 5 to 10 min to facilitate venous return (cool down). During each test, $\dot{V}O_2$ was measured using the open-circuit spirometric method and HR was monitored continuously using a 12-lead system (Quinton Q5000). Blood pressure was measured by auscultation prior to exercise and during recovery.

Statistical Analysis. Repeated-measures ANOVAs were used to compare pack systems on each of the outcome variables ($\dot{V}O_2$, HR, hip and shoulder velocity, acceleration, and displacement, trunk angle change, EMG, SOM, VIS, VEST, and PREF). If a statistical difference ($p \leq 0.05$) was revealed by the ANOVA, then a *post hoc* test was applied. A rank order of the pack systems on each of the outcome variables and a sum of the ranks will provide an index of performance for the various systems.

RESULTS

Anthropometric.

A series of measurements (shown in Table 3 [side view] and Table 4 [rear view]) were used to characterize the subjects used in this study. Part of the purpose of taking these measurements was to enlarge a database being created for U.S. Navy and U.S. Marine Corps personnel for use in studies in Ergonomics (human - equipment interfacing) and for design purposes for new equipment.

Table 3. The mean ± SD in centimeters (cm) for measurements taken of the side view of the subjects.

Crown of helmet to ear lobe	19.9 ± 2.3
Ear lobe to acromion process	21.0 ± 2.5
Acromion process to olecranon process	37.0 ± 5.2
Olecranon process to condyle of wrist	28.8 ± 3.2
Acromion process to trochanter	55.0 ± 6.2
Trochanter to epicondyle of knee	39.5 ± 4.1
Knee epicondyle to malleolus	42.5 ± 5.2
Malleolus to toe of boot	23.5 ± 1.7
Malleolus to heel of boot	9.5 ± .9
Toe of boot to heel of boot	31.4 ± 2.8

The body profiles are shown as a deviation from the "reference man" and reported as Z scores (Table 5) and graphed (Figure 15). The body profiles presented in Figure 15 show that the group of test subjects had less fat (skinfold thickness), larger girths, and larger breadths than the average or "reference" individual for this age category. This information in addition to the high mean level of aerobic fitness reported in Table 2 indicates that the group of subjects was very fit and were indicative of active duty U.S. Marine Corps male personnel. Individual information was used to calculate body somatypes.

Table 4. The mean lengths ± SD in cm for the measurements taken from the back view of the subjects.

Crown of helmet to cervical vertebrae 7 (C7)	27.4 ± 2.2
C7 to right acromion process	22.8 ± 1.8
C7 to left acromion process	22.9 ± 2.5
C7 to right trochanter	65.5 ± 7.2
C7 to left trochanter	66.8 ± 6.8
Right trochanter to right knee (posterior)	41.0 ± 3.8
Left trochanter to left knee (posterior)	41.0 ± 3.8
Right knee to right heel	49.3 ± 5.1
Left knee to left heel	49.5 ± 4.3

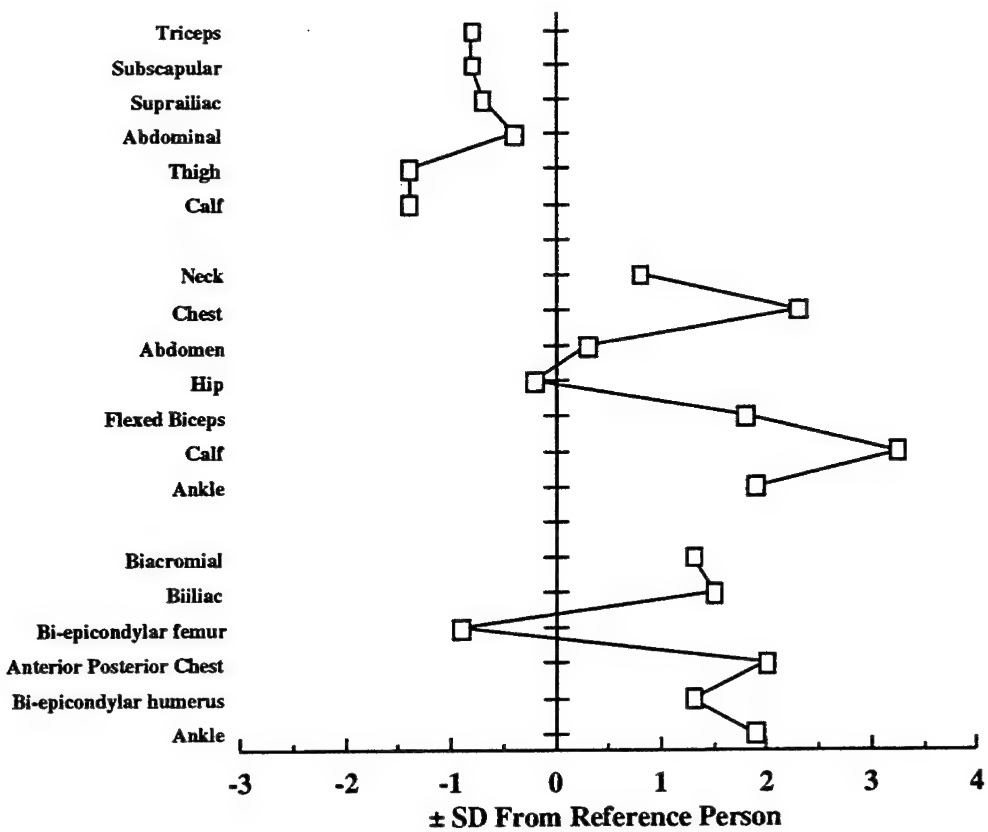

Figure 15. Body profiles (Z score) for the group ($\bar{X}$) of test subjects .

Table 5. Anthropometric measurements and their Z-scores ($\bar{X} \pm SD$)

Measurement	$\bar{X} \pm SD$	Z Score ± SD
Skinfolds (mm)		
Triceps	12.4 ± 3.2	-0.8 ± 0.7
Subscapular	13.8 ± 4.0	-0.8 ± 4.0
Suprailiac	12.9 ± 5.8	-0.7 ± 1.1
Abdominal	23.7 ± 9.5	-0.4 ± 1.2
Thigh	16.2 ± 6.3	-1.4 ± 0.8
Calf	9.9 ± 2.0	-1.4 ± 0.4
Girths (cm)		
Neck	37.9 ± 1.2	0.8 ± 0.7
Shoulder (at acromion process)	100.8 ± 5.6	
Chest (level of nipple)	97.7 ± 6.0	2.3 ± 1.0
Abdomen (at umbilicus)	84.7 ± 6.8	0.3 ± 0.8
Hip (largest)	97.8 ± 6.8	-0.2 ± 0.6
Flexed bicep	35.1 ± 2.3	1.8 ± 0.9
Calf	38.4 ± 2.1	0.7 ± 0.7
Ankle	26.5 ± 1.5	1.9 ± 0.9
Lengths		
Leg	92.4 ± 5.1	
Trunk	53.4 ± 3.8	
Torso	45.8 ± 3.6	
Breadths (cm)		
Biacromial	42.3 ± 1.7	1.3 ± 0.8
Billiac	27.4 ± 2.0	-1.5 ± 0.8
Bi-epicondylar femur	10.0 ± 0.3	-0.9 ± 0.9
Anterior-Posterior chest	21.2 ± 1.3	2.0 ± 0.9
Bi-epicondylar humerus	7.2 ± 0.3	1.3 ± 0.7
Ankle	7.7 ± 0.4	1.9 ± 0.9

A somatotype is defined as a type of body build based on appearance substantiated by measurements. The three categories of body types are: (1) endomorphic, (2) ectomorphic, and (3) mesomorphic (Sheldon, et al.,1940; Sheldon, et al., 1954). Endomorphy defines a type of body build in which tissues derived from the endoderm predominate. In this body type, there is a relative preponderance of soft roundness throughout the body with the body usually presenting a large trunk and thighs and tapering extremities. Ectomorphy defines a type of body build in which tissue derived from the ectoderm predominates. In this type of body build, there is a relative preponderance of linearity and fragility. This body type usually has a large surface area and thin muscles and subcutaneous tissue. Mesomorphy defines a type of body build in which tissues derived from the mesoderm predominate. In this body type, there is a relative preponderance of muscle, bone, and connective tissue. This body type usually has a heavy, hard physique of retangular outline. The mean somatype for the subject group was 3.75-5.73-1.56 (Endomorphy-Mesomorphy-Ectomorphy) and is shown in Figure 16 relative to elite male atheletes.

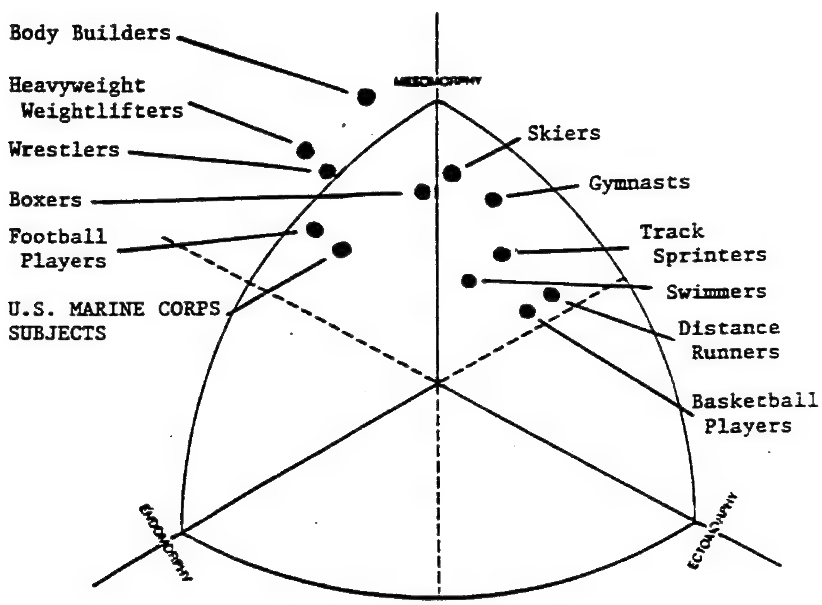

Figure 16. The mean somatotype for the test subject group in relation to somatypes for elite male athletes (adapted from Carter,1980).

Hydration.

Hydration was assessed before each trial by bioelectrical impedance measured across multiple frequencies. These measurements were used to calculate TBW (Figure 17). Statistical analysis of each individual over time indicated that hydration levels were well maintained as there were no statistical differences between subjects by hydration levels or by backpacks. The difference in size of the subjects (Table 2) contributed to the variability (Figure 17).

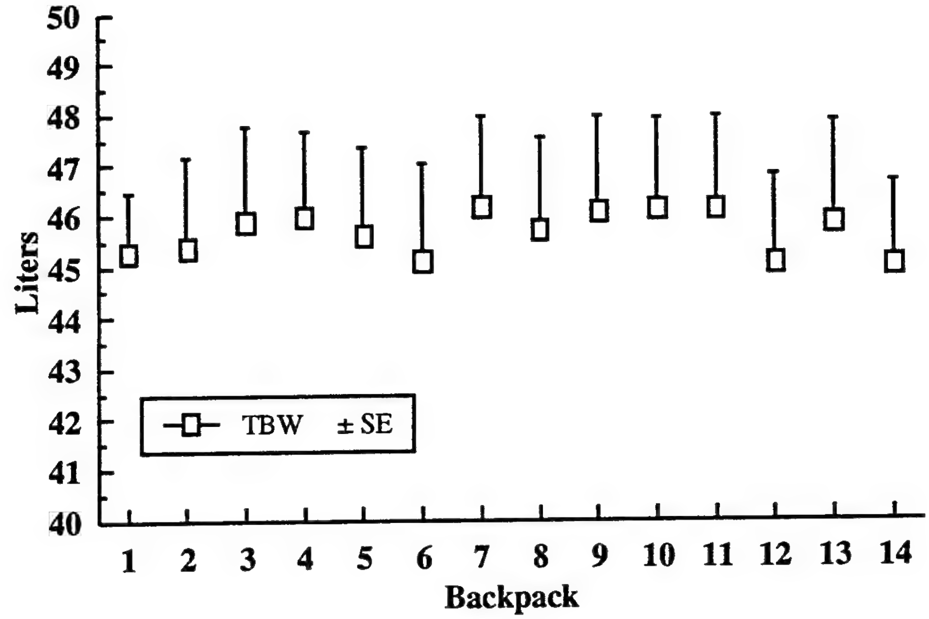

Figure 17. Total body water ($\bar{X} \pm$ SE) in liters calculated before each trial.

Backpack Preference.

Each subject was asked to rate each backpack (0 = worst and 10 = best). Every effort was made to correctly fit the packs to the individual but some packs were more adjustable than others. The data for individual preference of backpacks is presented in Figure 18 ($\bar{X} \pm$ SE). The eight highest rated backpacks were internal frame backpacks while the lowest rated backpack was the ALICE. Internal frame packs were rated significantly higher than the external frame (internal $\bar{X} = 6.8 \pm 1.5$, external $\bar{X} = 4.7 \pm 2.4$; $p < 0.001$).

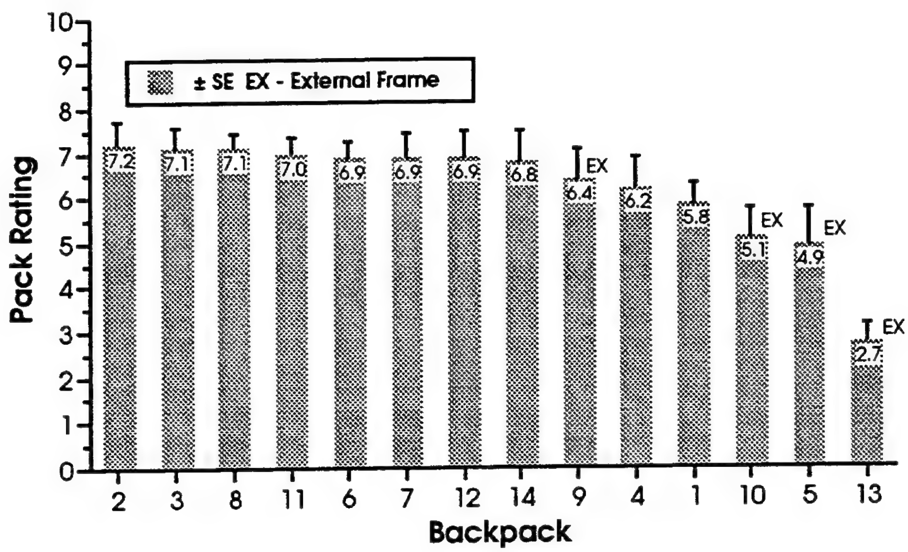

Figure 18. Score of 14 backpacks with 45.45 kg carried for up to 4 hr. Backpacks are listed by manufactures in Table 1.

Metabolic.

VO_2 was calculated twice during each hour of exercise during each trial. The mean values are presented in Figure 19. There was no statistical change from the beginning of the first hour (min 20) to the end of the first hour (min 45) or to the beginning of the second hour. From that point, the VO_2 values were elevated ($p \leq 0.05$) from the initial value. Metabolic changes were not backpack specific.

The pattern of change in HR is shown in Figure 20 ($\bar{X} \pm$ SE). There was a significant increase in HR over each 50-min walk, and only in the first rest break was there sufficient recovery of the HR to the subjects initial levels. All subsequent rest periods did not allow sufficient recovery time to restore the HR response to the initial level which was independent of the backpack used.

The pattern of change in respiratory exchange ratio (RER) is presented in Figure 21 ($\bar{X} \pm$ SD). RER is a reflection of the fuel source being used and is derived from the equation RER = $Vco_2 \div Vo_2$. There was no significant change in the RER over the duration of the trials for all backpacks.

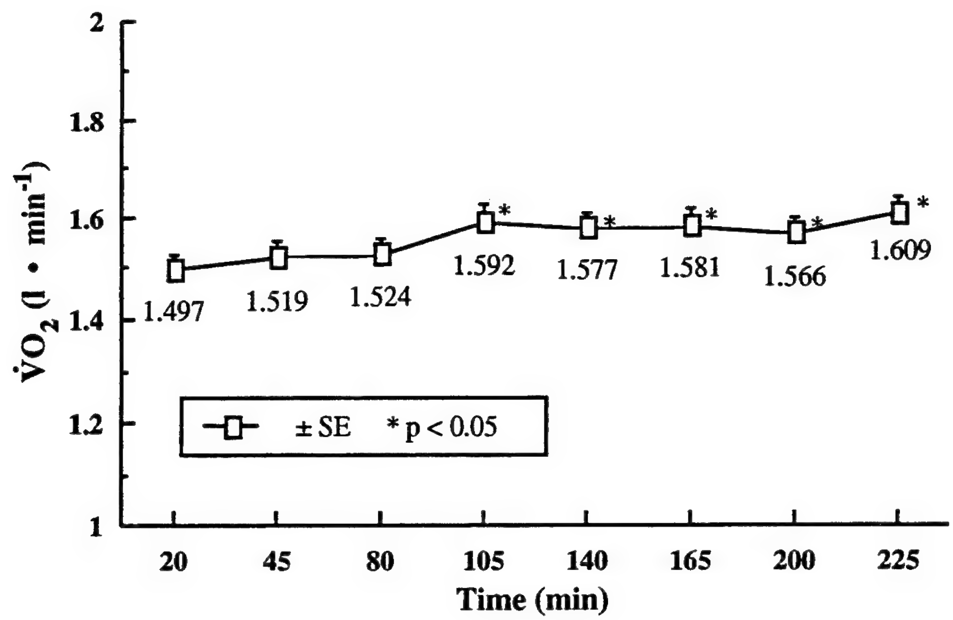

Figure 19. Oxygen uptake ($\bar{X} \pm$ SE) during the 4-hr trial.

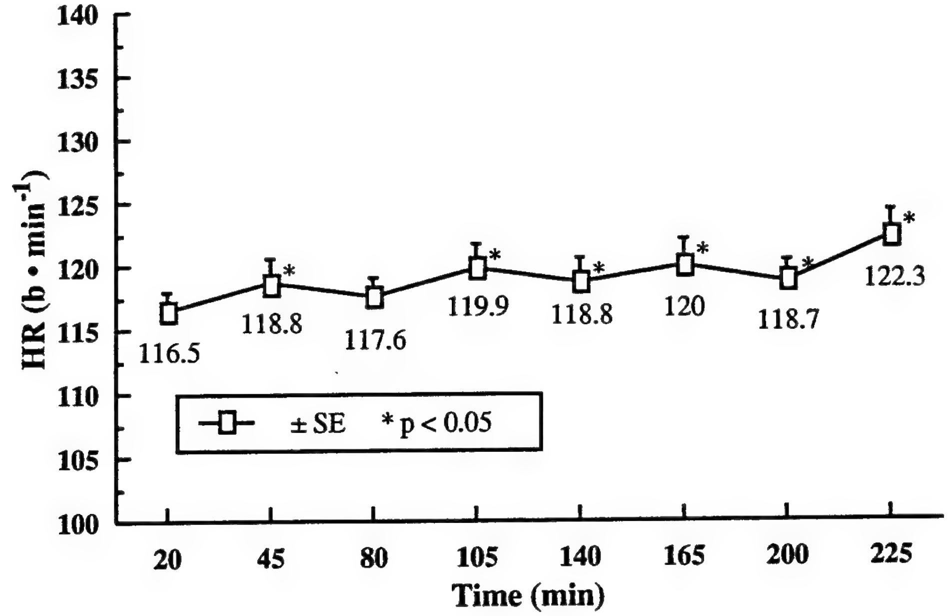

Figure 20. The change in heart rate ($\bar{X} \pm SE$) over the duration of the 4-hr trials

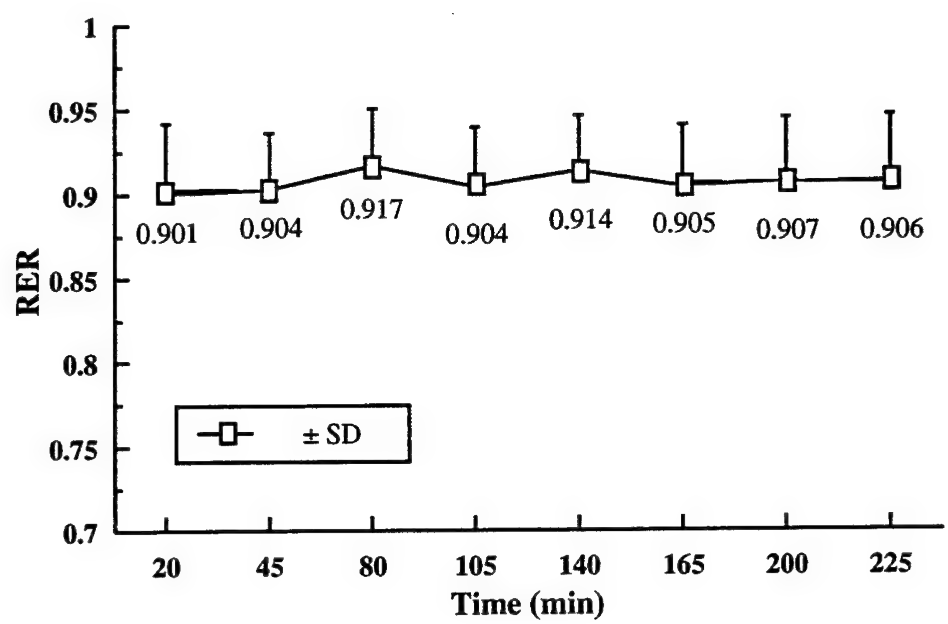

Figure 21. The respiratory exchange ratio ($\bar{X} \pm SD$) over the duration of the 4-hr trials.

Each subject was asked to rate the difficulty of effort which is expressed as RPE in Figure 22 ($\bar{X} \pm SD$). Although the values tend to increase over time, there was no significant increase in RPE.

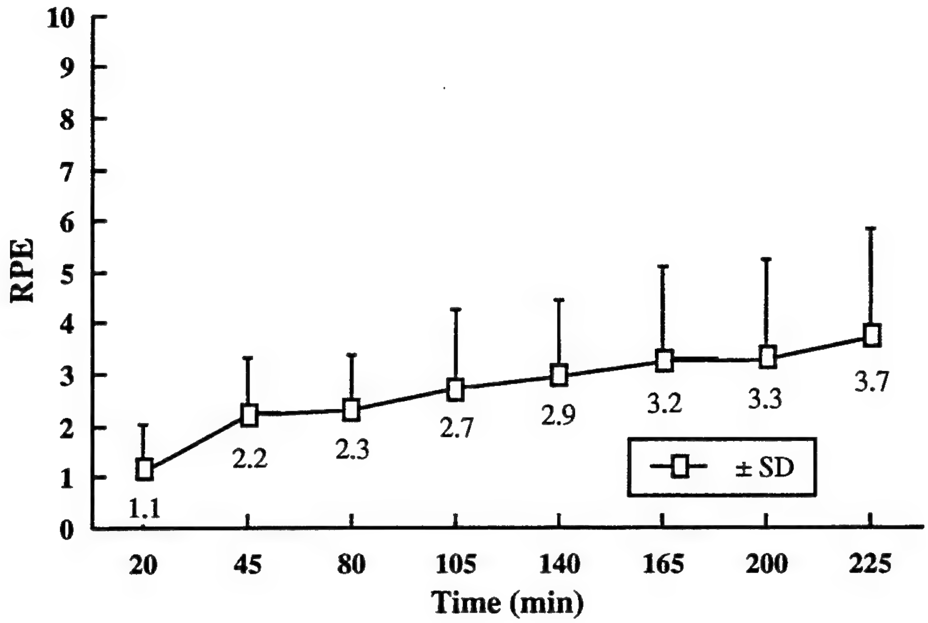

Figure 22. Rate of Perceived Exertion ($\bar{X} \pm SD$) for all trials over the 4-hr trial.

Postural Balance.

The sensory organization test scores are based on the assumption that a normal individual can exhibit anterior to posterior sway over a total range of 12.5 degrees without losing balance. The equilibrium scores were calculated by comparing the angular difference between the subject's calculated maximum anterior to posterior center of gravity (COG) displacement to this theoretical maximum displacement. For Figures 23 through 27, there are three values given for each backpack: (1) the unloaded value (triangle), (2) the loaded value before exercise (square), and (3) the loaded value after exercise (circle).

The equilibrium score is a culmination of input from all six conditions and is shown in Figure 23. It is evident that fatigue does exert an effect on the ability of the subjects to perform some of the stability tests. There is no consistent pattern of increased instability with the type of backpack or with the position of the backpack on the backpack ratings (Figure 18). There were significant differences (backpacks 1, 4, 6, 10, 12) after exercise but no difference between the loaded condition before exercise and the unloaded condition (Figure 23).

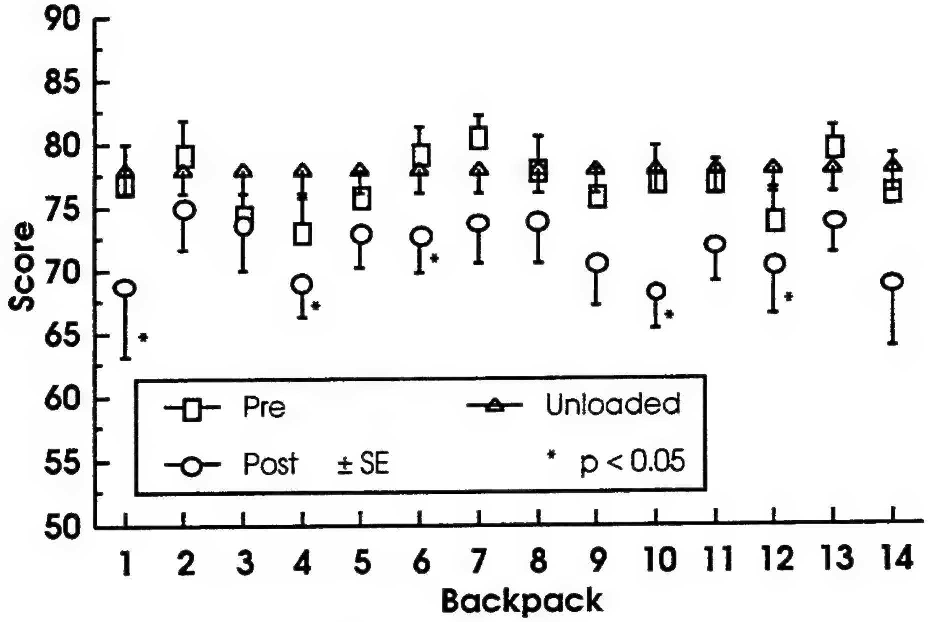

Figure 23. The equilibrium scores ($\bar{X}$ ± SE) for all backpacks in the loaded condition, before exercise, the loaded condition after exercise, and the unloaded condition.

The contribution of the somatosensory input (SOM Test) to the equilibrium scores are shown in Figure 24. A decrement in these responses indicate poor use of somatosensory references for maintaining balance. Results of a one-way repeated-measures ANOVA comparing all subjects for each pack, unloaded to loaded before and after the exercise session, did not show statistical differences for each backpack. In addition, paired t-tests for all SOM pretest and post test data were also nonsignificant. Therefore, fatigue does not effect the balance of normal healthy Marines when visual references are removed.

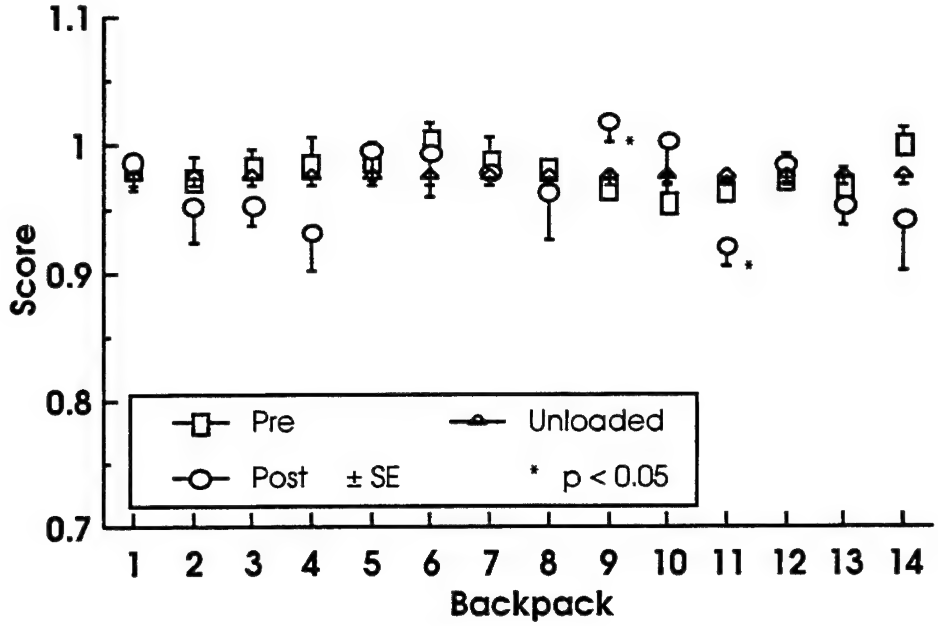

Figure 24. The effect ($\bar{X}$ ± SE) of the use of somatosensory input on maintaining balance (SOM Test).

The use of visual references (VIS Test) in maintaining balance when somatosensory or tactile cues are inaccurate is shown in Figure 25. Paired t-tests showed there may be a possible trend between pretest and posttest scores indicating that fatigue from carrying the equivalent of 100 lb for 240 mins affects the use of these cues on normal healthy Marines. However, results of the one way repeated measures ANOVA showed no significant differences between unloaded and pretest loaded and post test loaded for any of the packs.

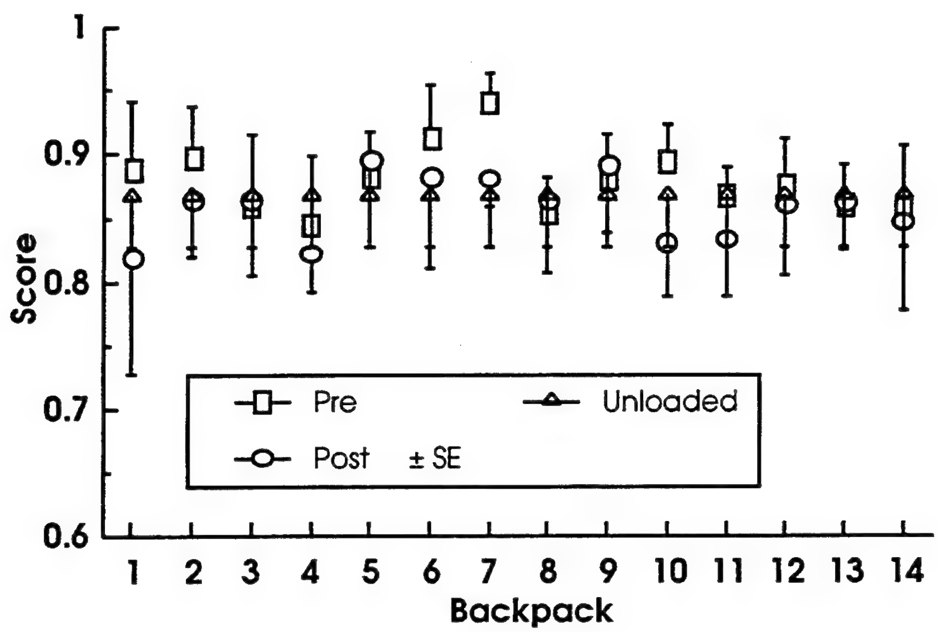

Figure 25. The effect ($\bar{X}$ ± SE) of the use of visual cues in maintaining balance when somatosensory cues are inaccurate (VIS Test).

The use of vestibular cues in maintaining balance is shown in Figure 26. Results of rank sum paired t-tests on pretest and posttest data showed significant differences ($p < 0.05$). Additionally, one-way repeated-measures ANOVA showed significant differences for pack 1 and pack 7 ($p < .05$) and a possible trend for pack 13. These data suggest that fatigue does affect the ability of normal healthy Marines to maintain balance when visual cues are removed and somatosensory cues are inaccurate.

The effect of the PREF Test (inaccurate visual cues, and inaccurate somatosensory cues) on maintaining balance, is shown in Figure 27. Results of paired t-tests indicate no significant differences between preexercise and postexercise PREF test scores. However, results of Friedman's rank test shows significant differences for packs 2 and 11 ($p < 0.05$) and a possible trend for pack 9. Interestingly, the following internal frame packs: 1,3,4,8,11,14 scored higher on post test trials then on pretest trials.

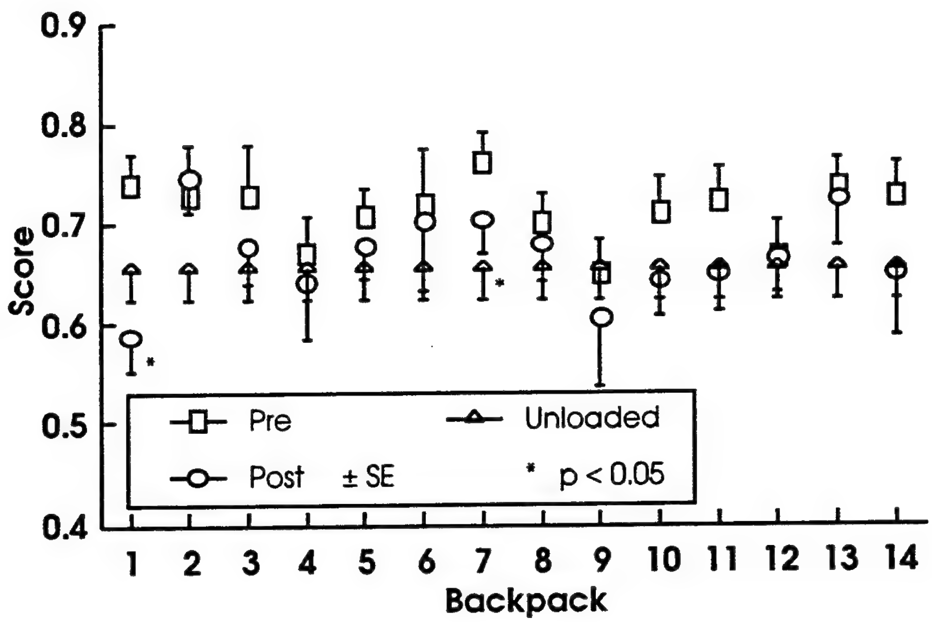

Figure 26. The effect ($\bar{X} \pm$ SE) of the use of vestibular cues in maintaining balance.

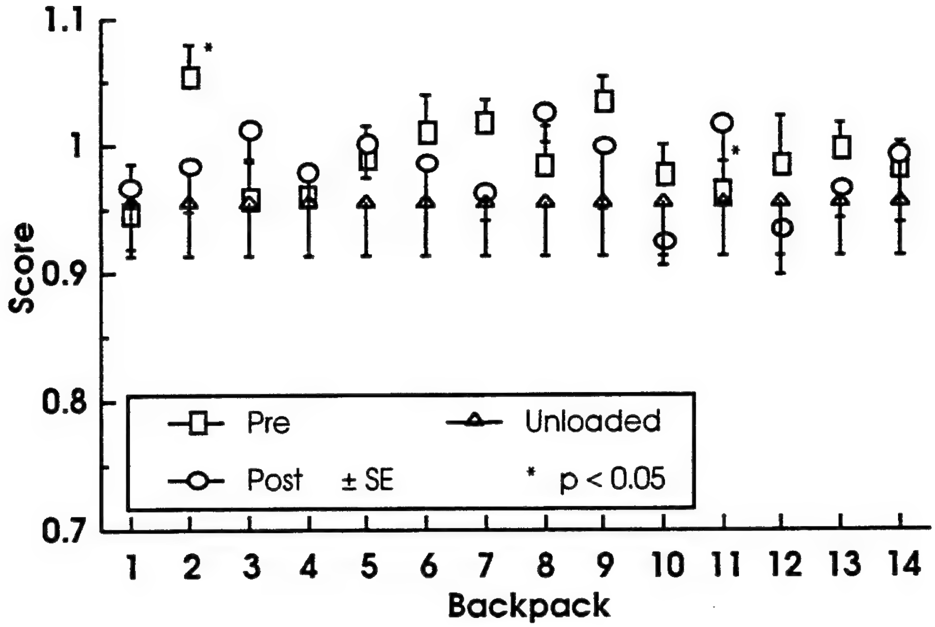

Figure 27. The effect ($\bar{X} \pm$ SE) of the use of inaccurate visual and inaccurate somatosensory cues on maintaining balance (Pref Test).

Electromyography.

For each muscle contraction, there are two major components (amplitude and frequency). The power density sprectrum (PDS) of the surface EMG signal expresses its energy content as a function of frequency. The PDS is compressed toward lower frequencies as a sustained muscle contraction occurs. The RMS is a measure of the amplitude of the muscle contraction. The increased amplitude observed with fatigue is due to the low-pass filtering effect of the body tissues on the surface EMG. An increase in the slope of the RMS (change in amplitude beween successive bursts of EMG) is considered to be an indicator of fatigue (Roy & DeLuca, 1989). The change in the RMS of the tibialis and the gastrocnemius was computed by deriving mean values for the mimimum and maximum values and calculating the change in the slope of these amplitude values over time. The minimum values for the anterior tibialis for four backpacks are shown in Figure 28 and the maximum values are shown in Figure 29. Using a repeated-measures ANOVA followed by Student-Neuman-Keuls *post hoc* test indicated that there was a significant difference between backpack 11 and backpacks 5 and 13 in the maximum values in the last hour. This indicates that fatigue in the anterior tibialis is greater in backpack 11 than in either 5 or 13.

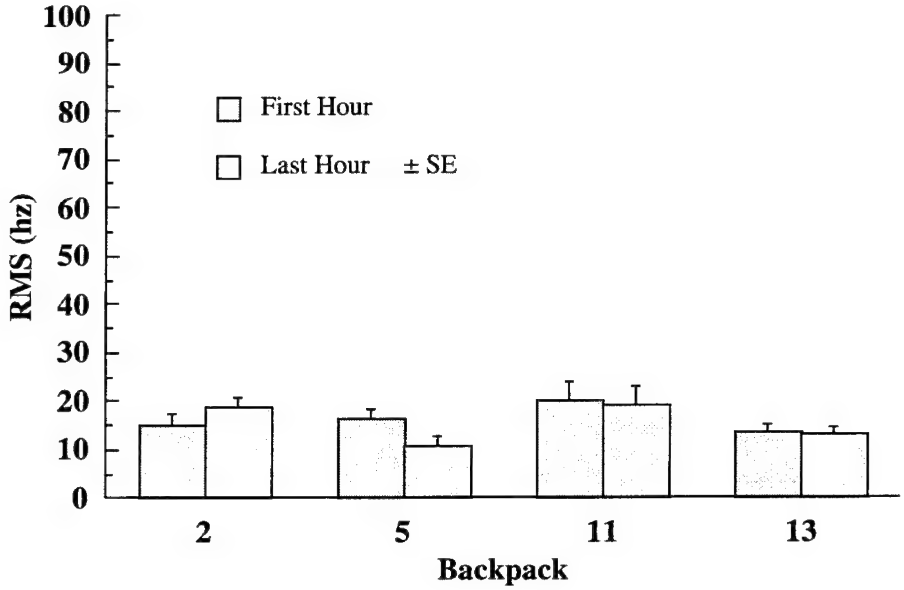

Figure 28. The minimum RMS ($\bar{X} \pm SE$) of the anterior tibialis muscle.

The same measurement of RMS in the gastrocnemius muscle (Figures 30 and 31) indicates that this muscle (a postural muscle) does not have the same pattern of change based on either the type of backpack or duration of exercise.

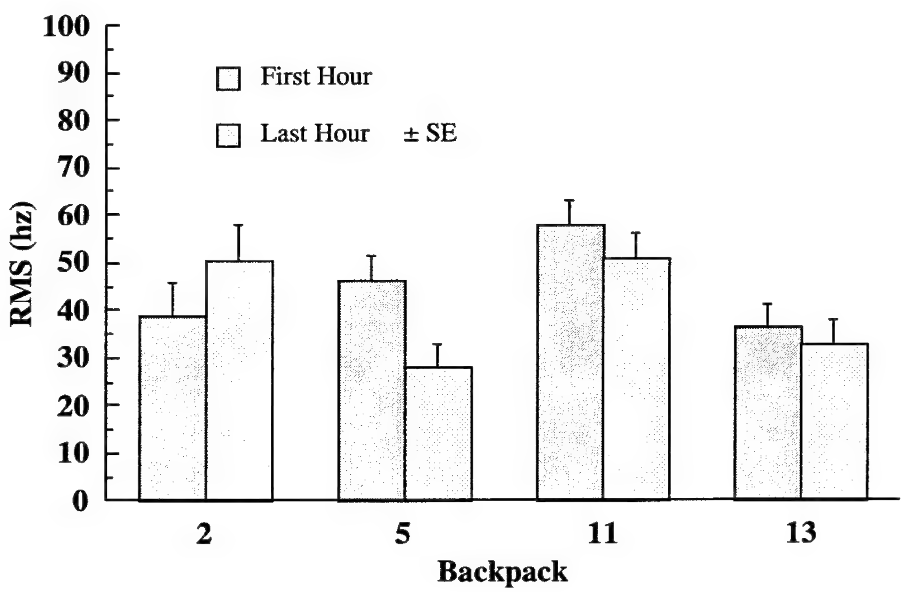

Figure 29. The maximum RMS ($\bar{X} \pm SE$) of the anterior tibialis muscle.

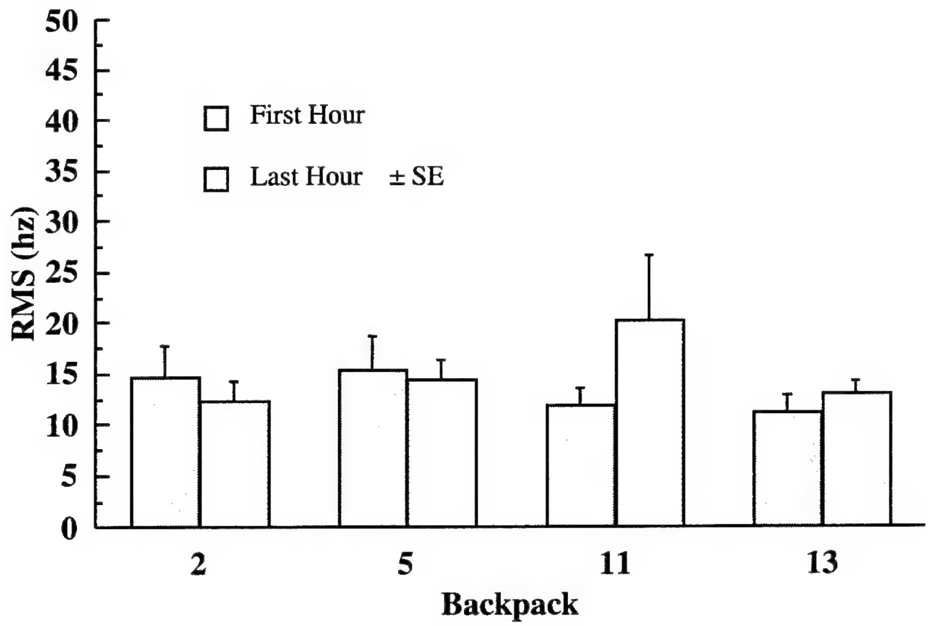

Figure 30. The minimum RMS ($\bar{X} \pm$ SE) of the gastrocnemius muscle.

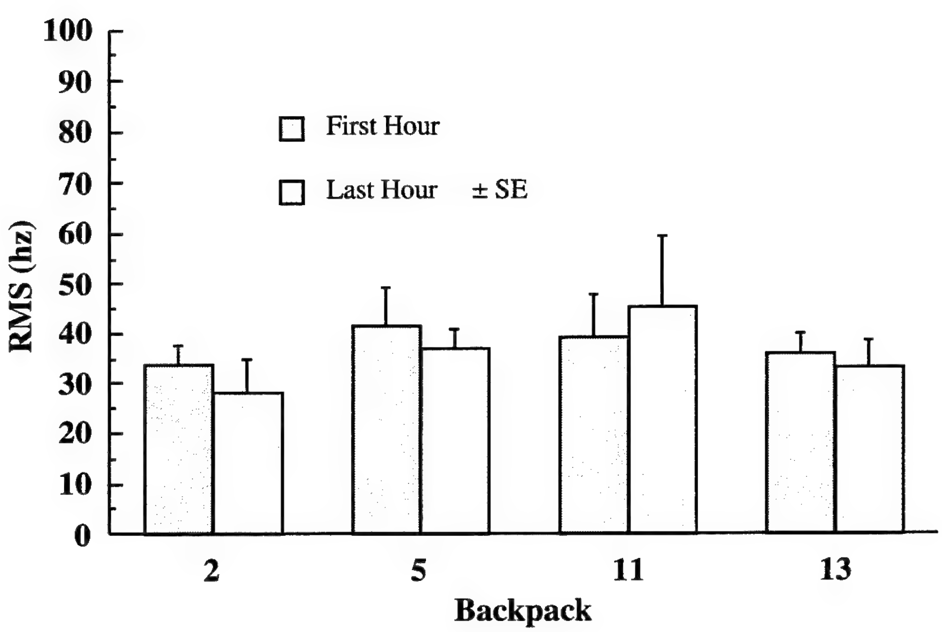

Figure 31. The maximum RMS ($\bar{X} \pm$ SE) of the gastrocnemius muscle.

Displacement of a marked joint indicates the amount of movement in either a vertical or horizontal plane. The use of a treadmill in this makes the interpretation of horizontal movement difficult since the moving belt can cause a backward sliding movement of the subject unrelated to walking. However, displacement in both planes is useful to indicate the swinging motion of the backpack as the subject walks.

Figure 32 shows a 10-s example of the vertical displacement of the hip point marker for the first and last hour of exercise. This figure indicates the oscillatory motion as the individual is walking and represents the type of motion exhibited by each marker. The combined values for the various directions of displacement for the hip and shoulder markers are shown in Figures 33 to 36.

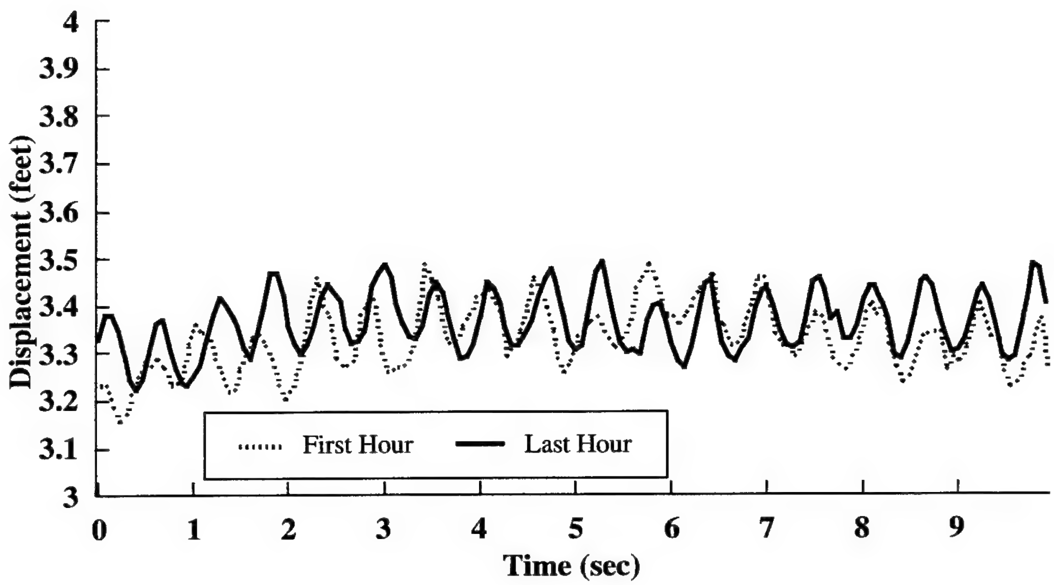

Figure 32. An example of the vertical displacement of the hip point marker in a single subject.

Statistical analysis (Figure 33) of vertical movement of the hip marker indicates that there was no difference between packs but there was a directional difference with an increase from the first to last hour across the backpacks. Analysis of the horizontal displacement (Figure 34) indicates there was no significant difference in the amount of movement of the hip marker between the first and last hour.

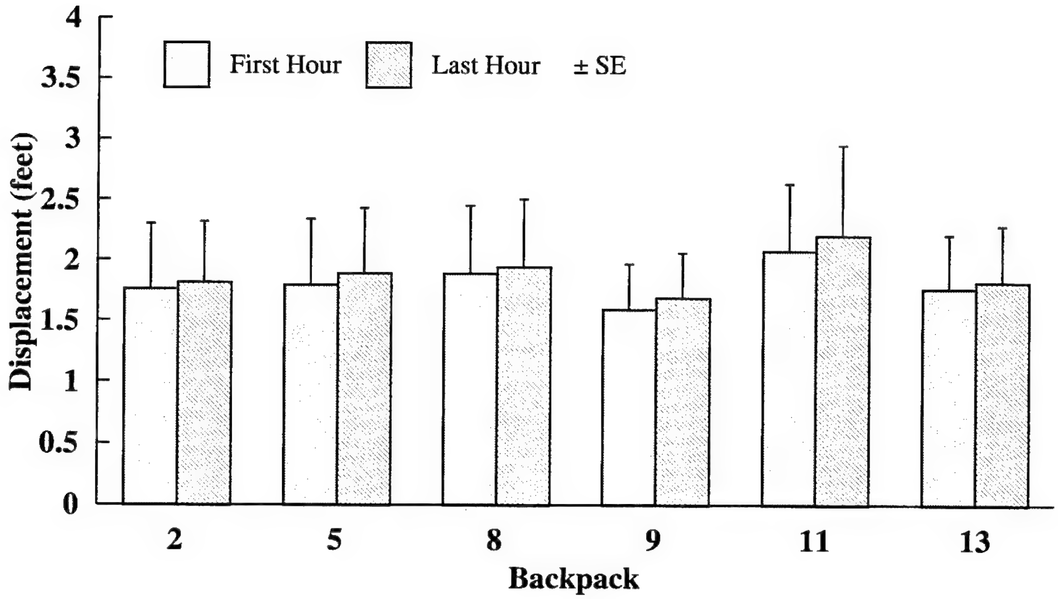

Figure 33. Vertical displacement ($\bar{X} \pm SE$) of the hip point marker.

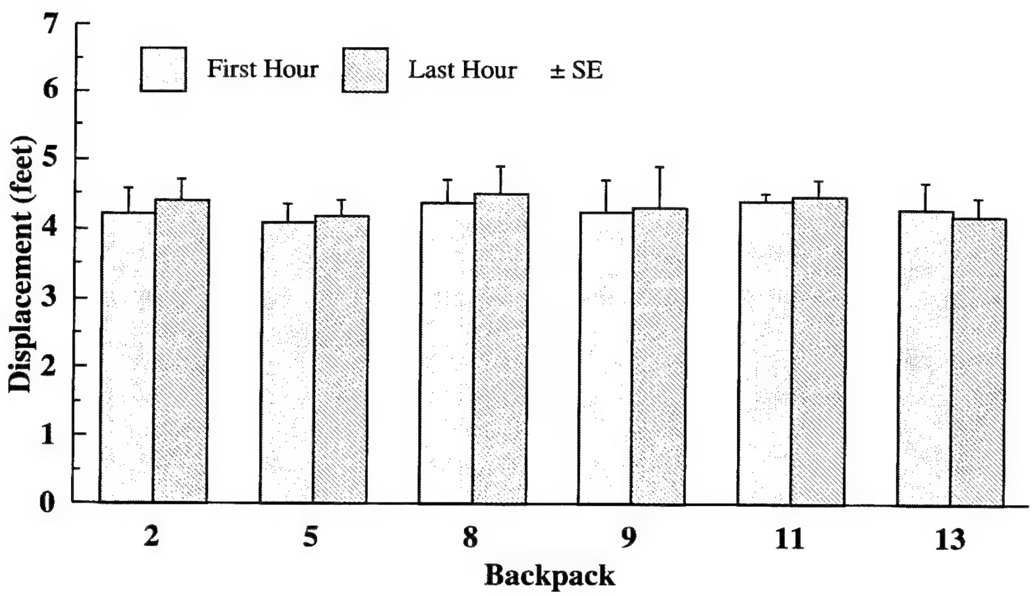

Figure 34. Horizontal displacement ($\bar{X} \pm SE$) of the hip point marker.

The vertical displacement of the shoulder marker is shown in Figure 35. There was no

significant difference across backpacks but the lowest rated backpacks show the lowest values. The horizonital displacement is shown in Figure 36. There was no significance difference between backpacks.

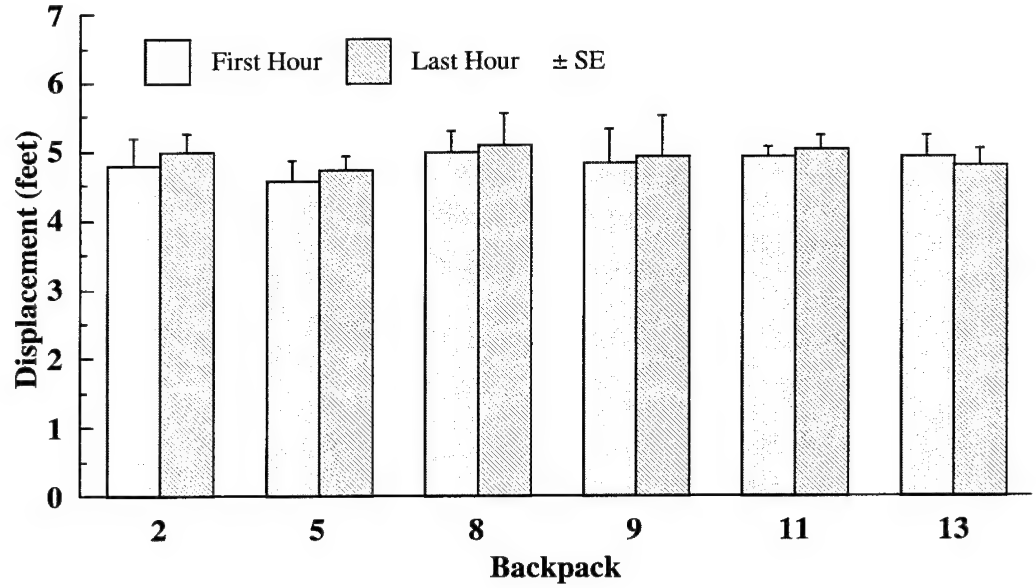

Figure 35. Vertical displacement ($\bar{X} \pm$ SE) of the shoulder point marker.

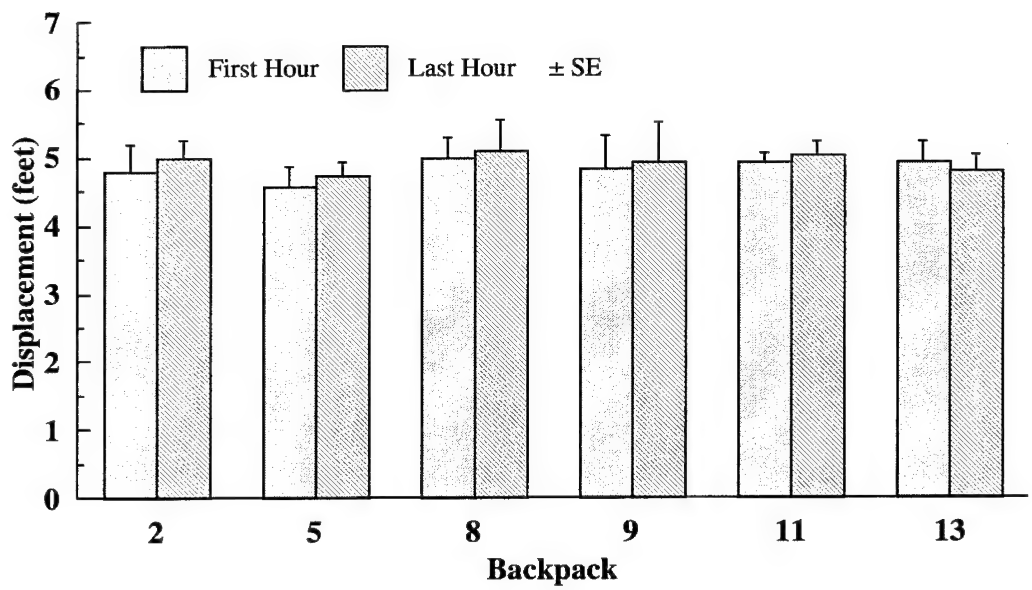

Figure 36. Horizontal Displacement ($\bar{X} \pm$ SE) of the shoulder point marker.

The means for the trunk angles are shown in Figure 37. The average angle for all

backpacks was 73 degrees or 17 degrees from upright. There was no significant difference between backpacks.

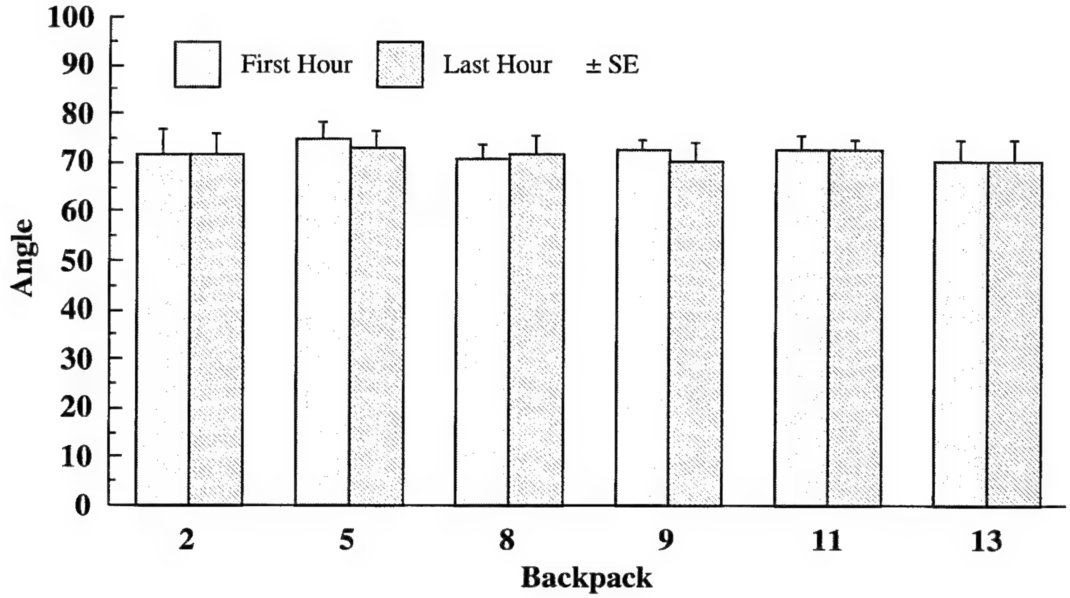

Figure 37. Change in trunk angle ($\bar{X}$ ± SE)

DISCUSSION

Many studies have observed the differences between various types of load carriage systems (Bedak, 1924; Durnin & Passmore, 1967; Datta & Ramanthan, 1971; Epstein et al., 1988, Haisman, 1988; Legg, 1985; Legg & Mahanty, 1985; Martin & Nelson, 1985; Martin & Nelson, 1986). Bedak (1924) found that there were physiological differences between loads carried in a yoke style across the shoulders, carried under the arm on the hip, on trays, in hand bundles, on top of the head, and on the shoulders. The yoke style across the shoulders elicited a lower Vo_2 response than any of the other mentioned conditions. This observation lead the authors to conclude that certain load carriage systems were more physiologically efficient than others. Kirk and Schneider (1992) tested internal and external frame backpacks. The authors found that despite the fact that the energy cost of exercise between these two types of backpacks was not significantly different, subjects rated these two backpacks differently on personal preference. These data supported another study which showed that metabolic measurements do not differ between types of backpacks (Winsman & Goldman, 1976). The current study revealed similar results. No physiological parameters were different between backpacks, but the Vo_2 and HR did increase throughout each trial. Similar results were found by Epstein et al. (1988), leading the author to suggest that altered biomechanics over time may be responsible for this increase in VO_2. In the present study, the load and walking conditions remained constant, so increases in metabolic work may have been due to muscular fatigue and additional muscle fiber recruitment needed to maintain the pace. It has also been suggested that an increase in body core temperature might be one reason why these parameters increase during prolonged exercise (Kalis et al., 1988), but that was not measured in the present study. Additionally RER, a reflection of both intensity of effort, and source of nutrients did not change over the 4 hr. One would expect this number to decrease over prolonged exercise indicating an increased use of fat and a decreased use of carbohydrates. The reason for this apparent stabilization of nutrient source is that subjects were allowed to consume carbohydrates and drink an electrolyte replacement drink while exercising and during each 10 min rest cycle. This was done so that diminished energy levels would not affect this test.

The psychological parameter (RPE) which involved the subjective rating of intensity of the effort was also not statistically different between the two types of packs (Figure 22). This was also reported in other studies (Kirk & Schneider, 1992; Patton et al., 1990). On close observation of Figure 22, the RPE's, although not statistically significant did rise during the course of the exercise session even though the workload did not change. This is probably related to the level of fatigue.

Legg (1985) concluded that the optimum method of load carriage should provide stability, bring the center of gravity of the load closer to the user's body, and make use of the larger muscle groups of the legs. Commercial manufacturers have used these findings to be competitive in the marketplace and have designed backpacks to provide greater stability, comfort and fit by placing the weight of the pack on both hips (allowing the weight to be carried primarily on the legs), and designing shoulder straps that stabilize (prevent rotation) the load. Additionally, many of these backpacks have been designed to be more adjustable in the length between the shoulder straps and

the waist belt (torso length). Conversely, some commercially manufactured packs had features that under heavily loaded conditions could not be utilized. Some packs were marketed as having easy adjustments that could be made while walking. Many of the subjects, despite being very fit and strong, were not able to make these adjustments without causing bodily harm.

This study examined 13 of the more than 150 commercially available backpacks; categorized as "medium backpacks", with a capacity of approximately 5000 cubic inches, and "features" that would allow the Marine Corps to carry gear, weapons, and provisions over varied terrain and climatic conditions. These packs were then compared to the ALICE pack. Features that distinguished certain packs above all others were: (1) stable and large waist belts that supported the load and distributed the weight over a large area, (2) adjustability for the subjects' different heights, (3) adjustment straps that moved the bottom of the pack upward and in, (4) load stabilizer straps which pulled the top of the pack into the back, and (5) flexible frames which allowed freedom of movement. These features were more successful on internal frame backpacks designed to carry the load closer to the center of mass of the body.

There were two backpacks (one internal and one external) that failed because of quality control problems. The Pioneer by Modan Industries (internal) had a waist belt buckle (other straps also had weak buckles but none popped open during use) that was too weak and popped open during use. The Peak 1 by Coleman (external) used a Kevlar frame that was too flexible. The design of the frame contained a flared lower portion which rubbed against the user and caused a friction problem. The flared portion also prevented the pack from being placed on the ground in an upright position. In addition, the waist belt was attached by a single row of stitching on each side which broke after a few hours of loaded walking.

The ALICE pack has some unique features that make it well suited for military use. It can be worn easily with the ITLBV, which is used to carry ammo and water. There are very few adjustments possible, making it relatively simple to use. As a result, the user can quickly and easily drop the pack and be able to carry out military operations. Since the need to carry military operational supplies will not change, either the ITLBV or the new replacement pack would need to be altered to accommodate military needs.

In this study, regardless of not finding differences in metabolic work between internal and external frame backpacks, subjects preferred the internal frame backpacks (Figure 18) for comfort, fit, and stability over the torso, shoulders and hips. This is similar to results seen by Bloom and Woodhull-McNeal (1987) where 9 out of 10 men preferred an internal frame backpack. Internal frame backpacks utilize two or three aluminum supports that are sewn into the back panel to provide rigidity and allow the load to be carried closer to the wearer's back. The ends of these vertical supports are attached to the waist belt which transfers the weight to the waist belt. External frame backpacks are hung on a rigid frame, usually metal, which rides close to the back but keeps the backpack off the body. In addition, the waist belt is attached to the frame rather than the frame being attached to the waist belt which moves the center of load away from the normal center of mass. Both the external and internal frame backpacks create a situation where the center-of-gravity of the user and load deviates from the user's unloaded center of

gravity (Kirk & Schneider, 1992). The further the load is carried from the user's COG the more muscular activity of the trunk is needed to maintain stable posture (Bobet & Norman, 1984). Thus internal frame backpacks should be more biomechanically efficient.

EMG data detected from the surface of the skin during sustained muscular contractions is a noninvasive method of looking at time-dependent modifications in muscular contractions (Roy & DeLuca, 1989). EMG signals represent the electrical activity generated by muscle fibers that are organized into motor units. With increased contraction, many motor units fire rapidly, forming a summated electrical response in which the motor unit action potentials interfere with one another (Gilia, 1989). Traditionally many researchers have reported an increase in EMG amplitude signals, and a decrease in the frequency spectrum when a contraction is sustained (Roy & DeLuca, 1989).

Analysis of the maximum and minimum amplitudes of the EMG data showed differences between the packs. The two leg muscles used for this study were the anterior tibialis and the gastrocnemius. These muscles were chosen because they provide the best information without causing discomfort and pain to the subjects. Back muscle fatigue could not be tested because the pain caused by the electrodes underneath the weight of the pack was not an acceptable option. The anterior tibialis muscle is a load accepting muscle that gets activated two times per step (initially as the weight comes down onto the foot and again as the foot pushes off) (Winter & Yack, 1987). The gastrocnemius is a plantarflexor muscle and is involved with maintaining the foot alignment while walking (Winter & Yack, 1987).

Analysis of EMG data showed that the anterior tibialis muscle fatigued more with certain kinds of backpacks. In comparing a highly rated internal frame backpack, Stillwater, with a poorly rated external frame backpack Peak 1, and the ALICE pack, it was found that the anterior tibialis muscle fatigued more with the internal frame backpack over the 4-hr duration of the trial. One explanation for these results is that the weight is shifted more onto the hips with the better backpack and the weight is retained more on the lower back with the poorer backpacks.
Backpacks that the subjects felt were uncomfortable and caused complaints concerning back pain produced a significantly smaller amplitude in the EMG in the anterior tibialis than those backpacks that were more favored. This difference in amplitude was significant in the fourth hour of exercise when compared between backpacks and was not significant for each backpack over time. This indicates that the change in the activity of the muscles was linked to the method of carrying weight and thus could be used to differentiate good backpacks from bad backpacks but not internal frames from external frames. In the backpacks that allow more weight on the shoulders than on the hips, the muscle fatigue will be seen in the lower back (Cook & Neuman, 1987) and therefore less fatigue in the legs. Therefore, when the weight is carried more on the hips, the tibialis muscle will fatigue more and the muscles of the lower back will be spared. The measurement of muscle activity in the weight accepting muscles is an easy way of possibly determining the potential for low back problems resulting from fatigue of muscles caused by load carriage. The EMG measurements in the gastrocnemius muscle did not show the same type of significant changes. The measurement of activity of primarily postural muscles will not produce indications of muscle fatigue or damage due to the fact that the gastrocnemius is a more powerful

muscle than the tibialis.

The NeuroCom Equitest® was used to answer the following questions: 1) does fatigue affect balance maintained from sensory organizational parameters; and 2) does a good backpack cause less fatigue to sensory receptors and postural balance muscles such that there will be a difference in the way subjects perform on tests designed to measure the effectiveness of sensory receptors and postural balance muscles? Analysis of the data indicated that the composite scores or the culmination of all the sensory input information did indeed fatigue pretest to posttest. By breaking the whole into its prospective parts it seems evident that the vestibular sensory receptors of the inner ear are the most affected by fatigue. COG or more correctly the center of pressure (COP) was measured (NeuroCom) before each test condition. These measurements indicated a shift in the COP between the loaded and unloaded group and an additional shift after work. The maintenance of balance during locomotion involves regulating the body mass (head, arms, and trunk) above the waist. When an additional loaded backpack is carried more on the hips, it should be easier to control than when the load is carried high. This is supported by the internal frame backpacks (as a group) performing better on the static postural tests than the external frame backpacks (as a group).

Video analysis data showed that the forward angle of trunk lean did not change over time or across the backpacks. It averaged 73 degrees for all loads. These results suggest that differences in the type of load carriage (external and internal frames) and load carriage differentiations (shoulder and hip load carriage) did not differ in the stance assumed by these subjects. There are several facts that may explain this result. The work was performed on an elevated treadmill (2% grade) which will tend to exacerbate the forward lean. The subjects used for this study were trained to carry heavy loads on a backpack (ALICE) that teaches a person to lean. In addition, the subject pool was small and the variation of body size within the pool was greater than desired. Increasing the total number of subjects or decreasing the variation could alter the measurements. The subject pool was selected to be divergent since that is representative of the U.S. Marine Corps. The above mentioned analysis was done on the side view only, data are now being analyzed to quantify the back, and the back and side views for a three dimensional analysis. Results of this analyses are still pending.

In summary, this study indicated that there are comfort differences between internal and external frame backpacks. In this case, the backpack frames that transfer the load to a more comfortable carry on the hips will be tolerated to a greater extent than those which carry the load further away from the body or higher on the back. While the data show that load carriage on the hips will produce more muscle fatigue in the load carriage muscles of the lower leg, it also may spare the muscles of the lower back. The lower leg muscles seem well designed to handle the stress of prolonged exertion. This is probably due to the muscle fiber type and muscloskeletal features of the lower leg that result in muscle lever arms that can withstand this type of stress. However, the lower back is ill-equipped to deal with heavy loads over prolonged durations and within the changing center-of-mass associated with walking. Since the load carried by the subjects (as a percentage of body weight) in this study exceeded the recommendations for recreational backpacking, it is possible that lesser loads would produce different results

(Jorgensen, 1988; Shoenfeld et al., 1977). This would probably be most apparent in the change in trunk angle. It is probably true that with extreme loads, there is no pack system (except the equal front and back pack) that would allow the person to stand more upright. However, if the weight transfer to the hips does relieve problems with the lower back muscles, it is an improvement over the current system since muscle injuries to the back are more limiting to performance than muscle injuries to the legs.

CONCLUSIONS

The ALICE backpack has many features that make it adaptable for use in military operations. However, the limitations of the pack and its probable role in causing injuries (e.g., rucksack paralysis) is sufficient reason to develop a new backpack for military use. The results of this study and other studies indicate that the load needs to be carried as close to the center-of-mass of the user as is possible. However, the use of a pack that distributes the load around the center-of-mass (e.g., equally in the front and back) will not prove feasible under military conditions. Therefore, the backpack frame that is chosen to meet the future needs of the military should transfer the weight to the hips and off the shoulders, have sufficient load adjustment straps that allow the load to be pulled into the body (to minimize changes in center-of-mass), and correctly fit the individual. The correct fitting (torso length) of the backpack frame to the individual was the most important factor in determining comfort and acceptance of a backpack. An otherwise excellent backpack that does not fit, will not perform and may actually cause more problems in the long run. Therefore, the backpack frame that is chosen will require multiple sizes and adjustability within each size. The foam in the waist belt needs to be of sufficient density to support the load (e.g., resist compression and deformation) and the waist belt connecting strap needs to be sufficiently large to prevent rollover. The lumbar pad needs to be firm but not so stiff it will cause lower back problems. The vertical frame components (stays) need to be supported by horizontal frame components to keep the pack in its intended shape irrespective of the size of the load. Design of the vertical frame components in order to transfer the weight to the sides of the hips rather than just to the low back would spread the pressure to the top of the hips and futher reduce the potential for low back problems. There is not a single commercial backpack ensemble that meets all of these requirements, but there are several commercial ensembles that incorporate some of the requirements and could be a good starting point for a new backpack system.

<u>Recommendations:</u> The best course of action is to design a new backpack system that will incorporate the following features. The frame should be designed to be near the center-of-mass (e.g., an internal frame design), be able to be fitted and adjusted, and allow the pack to be removed quickly while the individual continues to wear the load carriage system (frame, shoulder straps, and waist belt) which now incorporates pockets for water and ammo. By separating the pack from the load carriage components, it makes it feasible to issue a load carriage system to each individual as part of their standard equipment and then a back pack (different volumes for different uses) could be attached as needed. The attachment of the pack could involve the use of velcro or some other combination of fasterners. This system would move the weight off of the shoulders, improve the center-of-mass of a loaded pack, decrease the incidence of injuries caused

by ill-fitted equipment, and still allow the light infrantryman to perform their military tasks which involve movement and warfighting.

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this study was to evaluate 13 commercial load-bearing ensembles (LBE) in relation to the ALICE pack to determine the best load-to-individual interface for use by the U.S. Marine Corps. Each LBE was evaluated biomechanically (gait and electromyographically), physiologically (heart rate and oxygen uptake), and subjectively (perceived exertion and LBE preference). Subjects (n = 14) carried 100 lbs for 4 hr (50/10 walk /rest) at 2.5 mph and 2% grade. Physiological parameters increased over time but were not pack specific. Subjects rated the internal-frame design as superior. Internal-frame designs shifted the weight from the back muscles to leg muscles more than external-frame designs. The forward trunk lean was not pack specific at this weight. An internal-frame design (center-of-mass close to body) incorporating adjustments for fit (torso length) and load stabilization while carrying warfighting supplies (replace load-carriage vest) would be the optimal choice for a new LBE for the U.S. Marine Corps.

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